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The primary goal of the Acquisition Review Quarterly (ARQ) is to provide practicing acquisition professionals with relevant management tools and information based on recent advances in policy, management theory, and research. The ARQ addresses the needs of professionals across the full spectrum of defense acquisition, and is intended to serve as a mechanism for fostering and diseminating scholarly research on acquisition issues, for exchanging opinions, for communicating policy decisions, and for maintaining a high level of awareness regarding acquisition management philosophies.

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ACQUISITION REVIEW QUARTERLY

Defense Acquisition University

Volume II, No. 2
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EDITORIAL MISSION

The primary goal of the *Acquisition Review Quarterly (ARQ)* is to provide practicing acquisition professionals with relevant management tools and information based on recent advances in policy, management theory, and research. The *ARQ* addresses the needs of professionals across the full spectrum of defense acquisition, and is intended to serve as a mechanism for fostering and disseminating scholarly research on acquisition issues, for exchanging opinions, for communicating policy decisions, and for maintaining a high level of awareness regarding acquisition management philosophies. The *ARQ* provides insight to the acquisition professional and others in the Department of Defense (DoD), Congress, industry and academe who have significant interest in how the DoD conducts its acquisition mission. Acquisition Corps members and other readers from government, Congress, industry, and academe are encouraged to use the *ARQ* as their professional forum for discussion and exchange of policies, research, information, and opinions.

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NOTE:

Robert W. Ball, editor and progenitor of this publication, retired after 34 years of federal service on March 31. Mr. Ball first published the *ARQ* in the Winter of 1994, and with this edition will have brought five issues of the journal to press. He will be succeeded by James Wittmeyer, editor of the Pentagon *Early Bird*.

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Contents

Is DAWIA Worth It?

An Approach to Analyzing the Impacts

Dean (Dusty) Rhoads

The Defense Acquisition Workforce Improvement Act (DAWIA) has brought change, but is it worth it? This article provides information on DAWIA and suggests an approach for conducting a study of the impacts of implementing DAWIA.

INTRODUCTION

More than a year has passed since the last mandatory provision of the Defense Acquisition Workforce Improvement Act (DAWIA) became effective (October 1993). Results are beginning to surface, although the full effects of DAWIA implementation will not be known until the ramifications of a more highly qualified acquisition workforce have worked their way through the system. It is time to begin asking what the effects of DAWIA implementation on the DoD acquisition system and workforce have been and what are the costs associated with implementation. As with any new program initiative, structures and mechanisms are needed to collect the necessary data and to identify emerging trends. This article identifies an approach for conducting an evaluation of DAWIA impacts and costs, and for interpreting the results based on proven analytical techniques.

Mr. Rhoads is a 25 year veteran of DoD acquisition. He completed a successful Air Force career with an assignment as a professor at the Defense Systems Management College (DSMC) where he initiated and taught the Systems Engineering Management Course. Since then he has had a successful career in industry and is now at ANSER, a public service research institute, where he leads a Defense Acquisition Workforce Improvement Act project for the Defense Information Systems Agency. Mr. Rhoads holds degrees from Iowa State University, Boston State College, and The George Washington University. He is also a graduate of the Naval War College, Air War College, DSMC Program Management Course, and numerous other DoD acquisition management courses.

The first part of a DAWIA effects study would be a performance evaluation; that is, a structured assessment of the Act's actual or potential impacts on the acquisition system, its processes, people, organizations, and products. The primary goal would be to assess how well the objectives of DAWIA are being realized. The evaluation would be based on identifying criteria for success by establishing suitable measures of effectiveness (MOEs), determining which MOEs are most applicable to the problem (i.e., have the highest cause/effect correlation), and differentiating multiple effects from multiple causes. The second part of the study would be a resource analysis keyed to the measured effect of practical constraints (such as money, other resources, and time) on expected outcomes and achievable capabilities. In combining these two parts, this study resembles several other types of analyses, including tradeoff, risk-return, cost-benefit, and return-on-investment.

STUDY APPROACH

A carefully selected team of analysts should be assembled for a study of this scope. It should possess a broad mix of education, training, skills, and experience relevant to DAWIA, defense acquisition, and the analysis techniques involved. The team needs to build synergy and carefully consider all aspects of a problem to minimize surprises and to maintain objectivity. At all steps in the process, close and frequent contact with the DAWIA stakeholders should be maintained to ensure that the analysis remains on track and achieves its objectives.

The analysis starts with the problem statement as the premise for the study and follows these steps:

1. Define study objective(s);
2. Define problem domain and boundaries;
3. Identify MOEs;
4. Develop model;
5. Identify data to be collected and sources of data;
6. Collect data;
7. Analyze and interpret data; and
8. Report.

STUDY OUTLINE

Problem Statement

Since full DAWIA implementation was mandated to occur by October 1993, a detailed analysis of its impact can be undertaken now to develop the methodology and models and to collect baseline results. Follow-up studies can then be conducted annually and the results compared to the baseline data to identify trends in the impacts of DAWIA implementation. Annual studies can be accomplished after all Services and agencies have submitted their October 1994 DAWIA reports to the Defense Manpower Data Center (DMDC) and the data are available for analysis.

The basic process for the initial study is as follows:

- **Define study objective(s)**

  The purpose of analyzing the impacts of DAWIA is to determine empirically whether its objectives are being achieved. This requires tracing and analyzing the Act's legislative, statutory, and regulatory history to identify the underlying expectations. Study questions can then be formulated. For example, what is the effect of DAWIA implementation on the DoD acquisition process? What is the return or benefit anticipated from implementing DAWIA? The answers to these questions will provide decision makers with pertinent information to support informed budgeting decisions for DAWIA.

  Performance evaluation in this case would be accomplished in two phases, implementation and effects. For the implementation phase, how successfully DAWIA requirements (e.g., the requirement that critical acquisition positions be filled by Defense Acquisition Corps members) have been implemented across all DoD services and agencies would be evaluated. In the effects phase, an attempt would be made to quantify the impacts of DAWIA implementation on the DoD acquisition process (e.g., are Defense Acquisition Corps members better program managers than pre-DAWIA program managers?).

  To illustrate the methodology, we begin from the premise that an objective of DAWIA is to raise the qualifications of the defense acquisition workforce, since DAWIA requires acquisition personnel to have more education, experience, and acquisition training than was previously required. An implied assumption is that a more qualified workforce would have positive impacts on DoD acquisition programs and processes. One of the first questions to answer is this: have the qualifications of the defense acquisition workforce improved since DAWIA? (In statistical analysis terms, this is an

"activity" question.) The second, more difficult, question is whether the changes in the defense acquisition workforce have had any impact on acquisition programs and/or processes (an "outcome" question). This second analysis can only be concluded after determining that there have, indeed, been changes in the qualifications of the defense acquisition workforce that can be attributed to DAWIA implementation.

A resource analysis would follow each of the performance evaluation phases to identify the costs associated with bringing about changes in the qualifications of the defense acquisition workforce, as well as costs saved and/or avoided in acquisition programs and processes as a result of DAWIA.

- **Define problem domain and boundaries**

The problem's domain and boundaries are implicitly defined by the objectives of the analysis. This second step ensures that we explicitly understand what is, and what is not, part of the problem. Here we would determine whether to answer questions such as these: what is the nature of DAWIA's impact on the DoD acquisition process? Has it been effective? Beneficial? Worth the cost? Boundaries must be identified for both the implementation and effects phases of the performance evaluation and resource analysis.

Objectives must be structured to avoid defining problems in so broad a way that they cannot be solved. For example, one broad objective of this analysis is to determine if DAWIA has had positive effects on the management of acquisition programs. To be servicable, this objective must be broken down into multiple, well-defined, measurable questions that can be answered with some degree of certainty. For example, does ACQ 201 - Intermediate Systems Acquisition, a required course for Level II certification in the career fields of program management and communications-computers, provide effective training on cost control measures? If the questions are not appropriately structured and bounded, there is no way of assessing whether other outside influences are also affecting the observed results, and the questions become impossible to answer.

The first phase, implementation, would be easier to delimit than the less well-defined effects phase. Many complex variables affect the outcome of acquisition programs, some of which are beyond the control of the acquisition workforce. For example, if an acquisition program is behind schedule and over cost, is it due to problems with its acquisition workforce or to funding perturbations on Capitol Hill or both? These kinds of considerations would require

time to sort out and could hinder the ability to assess DAWIA effects on DoD acquisition. A further examination of this analysis of DAWIA outcomes may reveal that finding definitive answers would require greater investment than the potential benefits warrant. It may be more beneficial to identify a series of indicators of acquisition program success rather than focus efforts on unachievable results.

- **Identify measures of effectiveness (MOEs)**
  Which workforce qualifications or performance objectives need to be evaluated? The MOEs would be different for each phase of the study. For the implementation phase, the MOEs would be measures of workforce performance and qualifications, such as number of critical positions identified, critical positions filled by Corps-qualified personnel, and requested and/or approved waivers. Education, experience, and acquisition training data would be analyzed to identify trends before and after DAWIA.

  Identifying MOEs for the effects phase requires more study and analysis than warranted by this brief outline. A key question in the effects phase is whether a post-DAWIA workforce is accomplishing the acquisition business of DoD more effectively. The MOEs in this phase would be much more difficult to collect and analyze. They could include number of people required to accomplish various acquisition functions, size of organizations, and length and complexity of acquisition training courses.

  From a resource analysis perspective, in the implementation phase the study would measure the investment cost, and in the effects phase, the return on investment. The MOEs for the implementation phase could include the cost of acquisition training, the cost of reporting, and the cost of maintaining the DAWIA required data. For the effects phase, MOEs could include reduced personnel costs; avoidance of fraud, waste, and abuse costs; and cost savings through improved performance. All MOEs would be weighted by some form of dollar and/or time factor (i.e., before and after DAWIA comparisons of schedules, inspection discrepancies, resources consumed, etc.).

- **Develop model**
  Models of the implementation phase of the performance evaluation would be developed to assess whether or not DAWIA has affected the "activity" side of the house (i.e., changes in workforce qualifications). Models to measure the effect of positive activity results on acquisition processes and programs (outcomes) would

also be developed. The focus would be on simple models that illustrate major trends rather than on complex models, which tend to lose visible results in too much detail. All models would be amenable to sensitivity analysis and "what if" exercises. The models would also identify outside factors that might influence outcomes. Examples of such factors include acquisition reform, acquisition streamlining, force downsizing, new regulations, and budgetary constraints. Technology and tools could also be mitigating factors, especially the application of information technologies that increase acquisition process efficiency and effectiveness.

This methodology involves identifying dependent and independent variables and their relationships, activities, and outcomes. For example, which independent variables affect the qualifications and performance of the acquisition workforce (dependent variables)? If education, acquisition training, and experience are three independent variables, what is the relationship between them and the dependent variables? For the effects phase of the performance evaluation, the dependent variables from the implementation phase (workforce qualifications) would become the independent variables whose effect on dependent variables (acquisition processes and programs) would be identified. Sensitivity analyses could then be performed by varying the levels of workforce qualifications (i.e., mix of education, acquisition training, and experience) to identify the effects. For example, from a return-on-investment perspective, what is a minimum level of investment (in the independent variables) to realize any effect, or what level of investment provides the greatest return, or what level of investment yields the greatest percentage return?

- **Identify data to be collected and sources of data**

The MOEs, the activity and outcome measures, and the models would be the determinants in deciding what data to collect and analyze. We have activity measures and outcome measures, both of which have MOEs that are estimated by models. In the case of workforce qualifications, the data collected would include educational degrees, acquisition course completions, and experience. No new data reporting would be required. Data would be derived from the information presently collected on the workforce and reported to DMDC. The data collected would be both pre- and post-DAWIA implementation for comparison and analysis. The DMDC data would be compared with data from the Defense Acquisition University (DAU) to identify the number of graduates of various acquisition

training courses and the number of them who are now working in acquisition positions.

- **Collect data**
  The data would be collected and used to validate the hypothesized models. Data already being reported by the Services and agencies and collected by DMDC would be utilized to the utmost; no new reporting requirements are envisioned. Most, if not all, data needed to evaluate changes in workforce qualifications should be available from existing personnel systems and can be collected through programmed queries to the databases. Cost data would be collected from selected financial accounting databases in DoD.

- **Analyze and interpret data**
  Various statistical analysis tools, depending on the models chosen, would be employed. By using the tools and analyzing the results, we would identify changes in workforce qualifications attributable to DAWIA, associate causes and effects, and assess the value of effects in relation to the investment.

- **Report**
  Management level reports summarizing the process methodology and interpreting the results would be provided at the conclusion of the analysis.

SUMMARY

The DAWIA implementation is driving major changes in the way acquisition careers are managed and the way acquisition professionals are selected for assignments, promotions, and advancement. It is imperative that DoD decision makers fully understand the impacts of DAWIA implementation, not only on acquisition processes and programs but also on the people involved. A performance evaluation and resource analysis would help DoD ensure that DAWIA implementation is beneficial to both its people and its processes and is in the best interests of the Government.

This article outlines a methodology to provide both the qualitative and quantitative feedback that DoD executives need to make informed decisions regarding DAWIA. The study outline is a first step that does not answer all the questions, but confronts some of the difficulties involved in finding answers. The effort needs to be undertaken to generate unbiased, accurate, in-depth, and pertinent information concerning the merits of implementing DAWIA in the DoD.

Some Common Characteristics of the Minuteman I, Polaris A-1, and ALCM Developmemt Programs

Edmund H. Conrow

The "President's Blue Ribbon Commission on Defense Management," in 1986, identified three military programs, the Minuteman I, Polaris, and the Air Launched Cruise Missile (ALCM), as examples of defense programs with streamlined procedures that achieved accelerated (development) schedules typically associated with successful commercial programs. The Minuteman I, Polaris, and ALCM acquisition histories were examined to identify common characteristics and to determine if lessons learned can readily be transferred to other DoD programs to potentially improve the odds of program success.

INTRODUCTION

In 1986, the "President's Blue Ribbon Commission on Defense Management," , stated that, "It is clear that major savings are possible in the development of weapon systems if the Department of Defense (DoD)

Dr. Conrow is an independent management and technical consultant in Redondo Beach, California, specializing in domestic and foreign defense, space, and commercial projects. His clients have included the government, national laboratories, federally funded research and development centers and industry. He holds a PhD in general engineering from Oklahoma State University and a PhD in public policy analysis from The Rand Graduate School.

broadly emulates the acquisition procedures used in outstanding commercial programs."

The Commission also stated that, "It is clear from our earlier description that defense acquisition typically differs from this commercial model in almost every respect." It did name, however, the Minuteman I, Polaris, and (post-Milestone II) long-range Air Launched Cruise Missile (ALCM) as examples of defense programs with streamlined procedures that achieved accelerated (development) schedules typically associated with successful commercial programs.

Only the post-Milestone II portion of the ALCM program used streamlined acquisition procedures. The long-range ALCM program (AGM-86B) was effectively initiated as a result of the cruise missile Milestone II decision memorandum on January 14, 1977. Prior to this time, the long-range ALCM had only been a paper study. Now it was to be developed and given priority over the existing short-range ALCM (AGM-86A) the Air Force had been developing (Conrow, Smith, and Barbour, 1982). (Shortly thereafter, the short-range ALCM program ended.) The ALCM program was transferred to the Joint Cruise Missiles Project Office (JCMPO) as a result of the Milestone II decision memorandum. (The JCMPO was also created as a result of the Milestone II decision memorandum.) However, it was not until President Jimmy Carter canceled the B-1A program on June 30, 1977 and the September 30, 1977 memorandum from Undersecretary of Defense for Research and Engineering (USDR&E) Dr. William J. Perry to the Secretaries of the Air Force and Navy, that the JCMPO was given sufficient external support in order to implement a streamlined acquisition program for the long-range ALCM. The ALCM flyoff was initiated in the same Dr. Perry memorandum eight months after the program entered Full-Scale Development (FSD, now Engineering and Manufacturing Development or EMD).

The development program acquisition histories of the Minuteman I, Polaris A-1, and ALCM systems were examined to identify: (1) some common characteristics of these programs, and (2) whether or not the lessons learned can be transferred to other DoD programs to potentially improve the odds of program success.

COMPARISON OF MINUTEMAN I, POLARIS A-1, AND ALCM DEVELOPMENT PROGRAMS

The Minuteman I (Anderson, 1977), Polaris A-1 (Sapolsky, 1972, Navy Department, 1986 & Mitchell, 1987) and ALCM (Conrow, Smith & Barbour), program schedules are summarized in Figures 1, 2, and 3, respectively.

Some Common Characteristics of the Minuteman I, Polaris A-1, and ALCM Development Programs

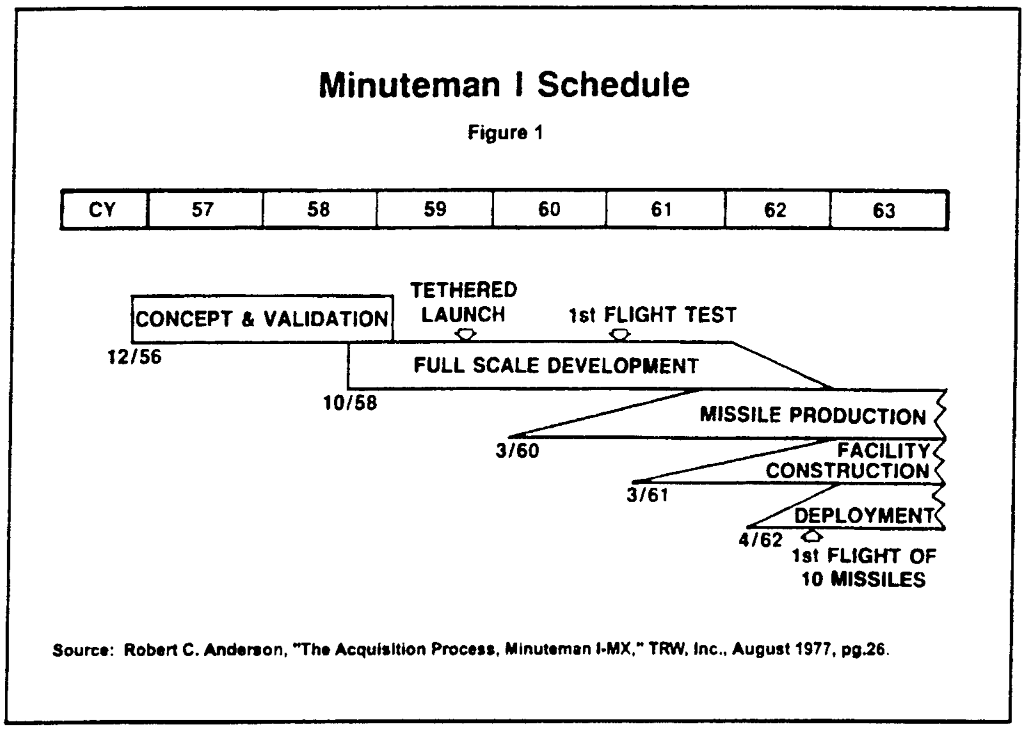


Figure 1. **Minuteman I Schedule**

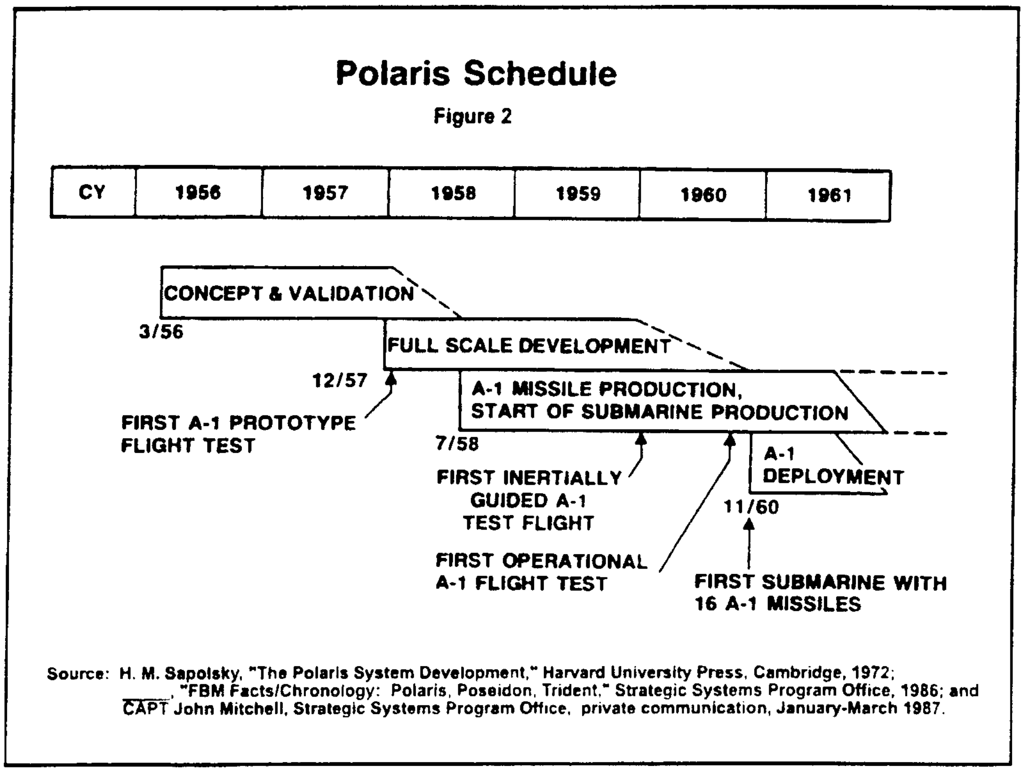
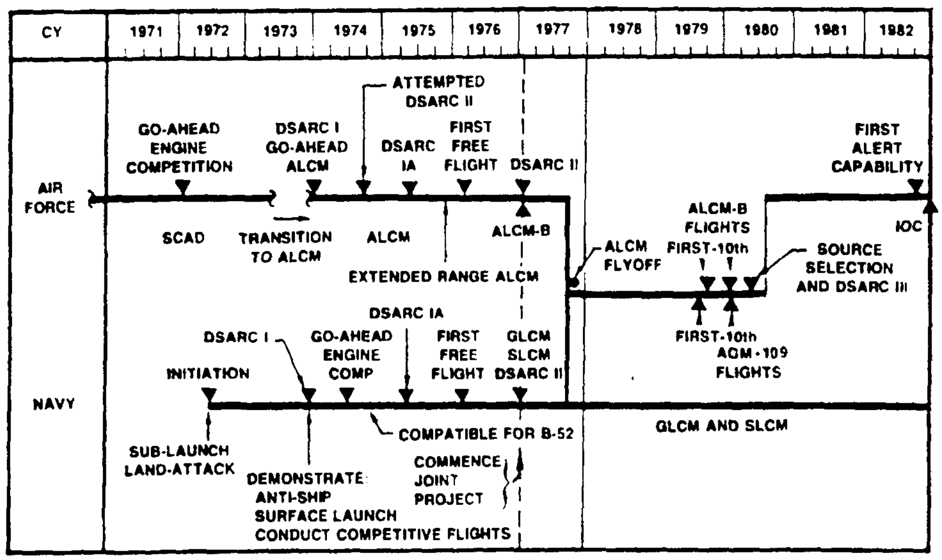


Figure 2. **Polaris Schedule**

ALCM Development History

Figure 3



EMPHASIS OF THIS ANALYSIS ON DSARC II (1/77) TO IOC PHASE

Source: Edmund H. Conrow, Giles K. Smith, and Allen A. Barbour, "The Joint Cruise Missiles Project: An Acquisition History," The Rand Corporation, R-3039-JCMPO, August 1982, pp. viii, 9, 11, and 62.

Figure 3. **ALCM Development History**

Priority Rating

Each program was of the highest national importance and held a BRICK-BAT DX priority rating. This rating provided assurance for availability of materials, components, and other resources (e.g., test ranges) in the event of conflict with commercial or lesser important defense contracts. The Minuteman I, Polaris (Fleet Ballistic Missile Program), and ALCM were assigned this rating in September 1959, November 1955, and February 1978, respectively.

Program Management Autonomy

Each program had considerable management autonomy. However, this did not prevent either bureaucratic encroachment or considerable programmatic turbulence from occurring during missile development (Minuteman I) or following development completion (Polaris A-1 and ALCM).

Conflicts between programmatic success and bureaucratic success exist and generally increase as a program nears completion. A potential cause of this problem is that tendencies towards suboptimization inher-

ent in project management are exacerbated when the urgency of the mission declines (Sapolsky).

In the Minuteman I case, Lieutenant General Bernard Schriever, USAF, was the commander of the Air Force Ballistic Missile Division, and the deputy commander of the Air Research and Development Center (ARDC, which later became Air Force Systems Command). In essence, Lt Gen Schriever was his own supervisor, which gave him very strong control over funding and review authority through 1958 (early FSD program phase). However, upon becoming ARDC commander in March 1959, Lt Gen Schriever abolished special management by exception for the Minuteman I program office and the program no longer possessed such uncommon reporting and protective mechanisms (Piper, 1962).

Minuteman I management independence had declined considerably just prior to the March 1960 production decision, as evidenced in an excerpt of a letter from Lt Gen Schriever to General Thomas White (Chief of Staff, USAF):

> . . . To insure a timely and effective force, our weapon system managers must possess the authority to effect necessary program changes. The continual encroachment upon this authority is of great concern to me, and I urge that you consider a return to the streamlined management principles which were so effective in the Thor and Atlas programs. (Piper)

By February 1961, the Minuteman I management situation had become so difficult that Lt Gen Schriever expressed great concern to Gen. White. Lt Gen Schriever felt that although the Minuteman program was a high risk program requiring unusual measures in all respects to protect the operational dates, the program was being managed in a routine fashion (Smith 1970).

Similarly, Major General Osmund J. Ritland, Commander of the Air Force Ballistic Missile Division, in a February 17, 1961 letter to Lt Gen Schriever, drew attention to how the Navy had been supporting the Polaris program. Maj Gen Ritland indicated that the Navy had rallied to support Polaris development, and that there had been no change in program management since the beginning of the program. The program director had been given total authority and resources to carry out his assignment. For this ". . . he had been asked for only one thing—results." (Piper)

The most important Minuteman I management strengthening measures occurred on February 23, 1961. General White informed all depu-

ties, directors, and chiefs of comparable offices that the Minuteman undertaking was a "... crash program." Therefore, all matters pertaining Minuteman high level program review were given "overriding priority," and reviews of the program were to be limited to a single review in the Air Staff with ARDC participation. (Piper)

In the Polaris case, the Special Projects Office quickly learned that a reputation for managerial efficiency made it difficult for anyone to challenge the Polaris development plans. Using the Program Evaluation and Review Technique (PERT), a computerized planning, scheduling, and control technique first made public in mid-1958, the Polaris Management Center, and other management innovations produced a protective veneer to allow Polaris development (Sapolsky). The degree of program protection provided by these innovations was of equal or greater value than the intrinsic management efficiency benefits of the techniques. They allowed the technical staff to work relatively unhindered and protected them from concerned but potentially outside officials.

Decentralization and competition were key components of the Polaris management strategy, which provided nearly self-regulating control over the Polaris development and its developers. Through decentralization, authority to act was given to those closest to the problems, yet competition among the program office branches and contractors assured the central staff that decisions affecting the vital needs of the entire system would be brought to their attention (Sapolsky). However, Department of the Navy restructuring in 1963 and 1966 eliminated much of the Special Project Office independence and management by exception (Sapolsky). Although this did not greatly affect the Polaris series of missiles (A-1, A-2, and the initial A-3), it did impact all subsequent Navy ballistic missile programs.

An Executive Committee (EXCOM) was established by USDR&E Dr. Perry, in September 1977 (early in FSD) to provide programmatic and fiscal direction to monitor the progress of the ALCM flyoff and other cruise missile variants. The EXCOM was not a voting group; rather its purpose was to review and discuss in an attempt to establish a consensus. In the absence of a consensus, Dr. Perry would act as required and report dissenting opinions to the Secretary of Defense along with recommendations for action. Normal channels remained open to the Services to express dissent. Another EXCOM feature was that it provided a forum for an expeditious review of problem areas. In addition, through its high-level OSD and Service membership and the use of action item assignments, EXCOM interaction with the JCMPO could potentially minimize program cost and schedule risk (Conrow, Smith & Barbour).

The EXCOM was a key element in the JCMPO management approach. In practice, the EXCOM served several functions. One function was to provide a periodic and structured forum for examining problem areas. Another function was that the EXCOM members had enough authority to resolve problems quickly, including resolution of funding shortages (Conrow, Smith, & Barbour).

The ALCM began transitioning back to the Air Force from the JCMPO following its Milestone III review in March 1980. The cruise missile project EXCOM was discontinued after its final meeting on January 8, 1981. After that, the JCMPO director had no effective formal mechanism for resolving issues between the Air Force and Navy.

Although the demise of the EXCOM did not affect ALCM development, it did potentially impact development of the Air Force Ground Launched Cruise Missile and the Medium Range Air-to-Surface Missile programs. Another effect was a psychological one in the minds of some JCMPO staff members and associated service officials and some personnel took this action to mean in part that the level of Office of the Secretary of Defense (OSD) support for the cruise missile project had diminished. Although impossible to quantify, this factor undoubtedly had some nonbeneficial impact on the cruise missile project (Conrow, Smith, & Barbour).

Early Program Support

None of the three programs received substantial support until the middle development stages. For example, the Minuteman I and Polaris programs were initiated after the four "approved" ballistic missile programs—Atlas Intercontinental Ballistic Missile (ICBM), Titan ICBM (backup), Thor Intermediate Range Ballistic Missile (IRBM), and Jupiter IRBM—were identified by President Dwight D. Eisenhower and the DoD in September 1955 (Sapolsky). In addition, early attempts to accelerate the Minuteman program schedule were not well received. Just prior to the Minuteman I FSD start and 11 months after the first Soviet Sputnik was launched, W. M. Holaday, Department of Defense Director of Guided Missiles, wrote to James H. Douglas, Secretary of the Air Force, on September 17, 1958, noting that the Minuteman program:

> . . . is not in consonance with my desire for an orderly step-wise development program. The plan submitted is characterized by the compressed development schedules associated with the so-called crash programs such as Atlas and Titan which, while justified by the urgency of the requirement for an early ICBM capability, are not con-

ducive to maximizing operational effectiveness or minimizing costs. (Piper)

Minuteman I had a less hectic development program than the Polaris A-1, partly because it was in the awkward position of being competitive with more advanced liquid-fuel ballistic missiles that were being developed by the Air Force. Essentially, all the critical uncertainties of Minuteman technology were reasonably well in hand by 1957, but activating a full-scale development program would inevitably cause a diversion of effort from the other ballistic missile programs to which the Air Force had commitments. Before Sputnik cut the purse strings, Minuteman I could have been developed only at the price of limiting expenditures of the Atlas or Titan programs (Perry, 1967). The effect of the Sputnik furor in late 1957 and of the political squabbling that sputtered through the next three years was, in part, the accelerated development of the Minuteman I and Polaris A-1 programs.

Similarly, by March 1957 the Navy's Special Projects Office had settled on the general specifications of the Polaris missile, submarine, undersurface launch system, and related components. Acceleration of the original program and substantial funding authorizations followed Sputnik. Cutting rather more than two years from the earlier schedules was achieved by compressing schedules, eliminating test sequences, and by relaxing both the range and accuracy specifications (Perry).

The long-range ALCM faced initial opposition from parts of the Air Force in favor of its much higher priority B-1A coupled with the short-range ALCM prior to President Carter's cancellation of the B-1A on June 30, 1977 (Werrell, 1985).

In addition, none of the programs had considerable opposition from the scientific community beyond the early development stage.

Program Funding and Funding Turbulence

While each program received the necessary funding, potential funding shortfalls occurred, producing program turbulence in the short run.

In the Minuteman I case, an accelerated development plan was approved on May 20, 1959 (mid-way through FSD). By November 1959, the Minuteman I contractors were reporting the potential for large cost increases. The cost increases were the result of externally directed changes to the Minuteman program, including the accelerated schedule. Initially, the corresponding increases in the program budget did not match these externally directed changes, and substantial increases in Minuteman I funding were necessary during the early portion of the missile production phase in FY60-FY62 (Piper).

In the Polaris case:

> An unexpected technical crisis would force internal reprogramming of funds to be undertaken. But inevitably money for all important activities was found, even if the lost time could not always be recovered. Program officials learned quickly to request generous contingency appropriations. (Sapolsky)

On December 9, 1957 (at the start of FSD), the Secretary of Defense authorized acceleration of the Polaris program to deploy the first Polaris weapon system in 1960. Shortly thereafter, on February 12, 1958, President Eisenhower signed the FY58 Supplemental Appropriation Act, including funds for construction of the first three Polaris submarines. Construction had begun in January 1958 using funds "borrowed" from other Navy programs (Navy Department, 1990).

In the ALCM case, the FSD program flyoff completion date slipped approximately three months during the course of the competition (from November 1979 to February 1980) because of the late receipt of the FY78 supplemental appropriation (Conrow, Smith, & Barbour), which was dedicated to the ALCM program.

While it is difficult to estimate accurately the impact of program acceleration on the development cost, the resulting increases were not minor for Minuteman I and ALCM. In the Minuteman I case, it is estimated that program acceleration added roughly 45% to the development phase cost, and was used for overtime for contractor employees and dual sources for critical items and tests (Anderson). In the ALCM case, a 41% cost growth occurred in the development phase—the largest contributors to this growth were the accelerated FSD schedule and some additional requirements imposed during the flyoff (Conrow, Smith, & Barbour).

Necessary Technology Advancement

Each program represented a moderate technology advance required across the entire system, with a considerable advance in the state of the art required for only a few subsystems. In addition, each program was the beneficiary of important advances made from prior technology, development, or operational programs.

For example, in the Minuteman I and Polaris A-1 programs, important advances had already been made in the Atlas, Thor, and Titan ballistic missile programs, including reentry physics, development of electronic controls, and inertial guidance. In addition, key solid propulsion

research had been started in the mid 1950s that provided an excellent bridge to Minuteman I and Polaris A-1 requirements. The "breakthrough" for each came in 1955 (prior to the commencement of either program) with demonstrations that large-grain, double-base solid propellants could be reliably ignited and burned (Perry)

In the ALCM case, key turbofan engine development had begun almost five years before the January 1977 Milestone II decision to initiate development of the long-range ALCM (Conrow, Smith, & Barbour). Likewise, the guidance system Inertial Navigation Element (INE) was closely related to a unit that had already been developed and tested for the F-15 and other military aircraft. In effect, the technical characteristics of both the ALCM engine and INE were well in hand prior to the cruise missile Milestone II decision on January 14, 1977.

Common areas of technology advancement used by all three programs included improved propulsion and warheads.

Some common key technology areas for the Minuteman I and Polaris A-1 that required moderate development included: (1) high energy, solid propellants with advanced binders and additives, and uniform character, which provided improved thrust and reliability; (2) improved materials (e.g., with increased strength and reduced weight), which contributed to increased range; (3) thrust vector control and thrust termination devices, which improved missile accuracy; (4) ablative reentry vehicle development, which reduced payload weight and reentry dispersion, and increased accuracy; and (5) reduced thermonuclear warhead weight, which reduced payload weight, thus increasing range, for a given warhead yield.

The ALCM key technology areas included: (1) a low specific fuel consumption, high thrust, small volume turbofan engine with high altitude startup, which increased range; (2) a special warhead design; (3) a low observables air vehicle, using a special airframe, missile radar altimeter, and engine design, which increased survivability; and (4) terrain contour matching and terrain following software, which increased missile accuracy and survivability.

Missile Thrust/Weight Ratio

The initial thrust/weight ratio associated with engine propulsion, coupled with missile weight, proved to be optimistic for each program. This led to a decrease in range for the first wing of Minuteman I deployed and the Polaris A-1, and is indicative of an initial set of system requirements that exceeded the feasible level of performance that could be achieved for the estimated level of cost and schedule.

Sacrifices versus desired performance levels were made for each pro-

gram in order to meet the initial deployment schedule. For the Minuteman I and Polaris A-1, a reduction in performance occurred along with an increase in development phase cost in the Minuteman I. Approximately 60 percent of the range reduction in the first Minuteman I wing was corrected in the second Minuteman I wing deployed in 1963, and virtually all of the Polaris A-1 missile range reduction was removed in the Polaris A-2 missile. The range (performance) reduction was accepted in the first Minuteman I and Polaris A-1 missiles deployed in order to reduce program schedule risk. In the ALCM case, no early attempt was made to correct the problem since the demonstrated performance level was adequate. The government emphasis in the ALCM program was to ensure the eventual production delivery schedule while maintaining development phase cost and performance.

Use of Parallel R&D

Parallel research and development (R&D) and simultaneous exploration of several alternatives were used extensively as risk reduction measures for selected key technology areas that required considerable advances in the state of the art. Parallel R&D had been recognized by this time as a key tool for reducing program risk when technology advances were required, particularly on a short schedule (Klein, Meckling, & Mesthene, 1958).

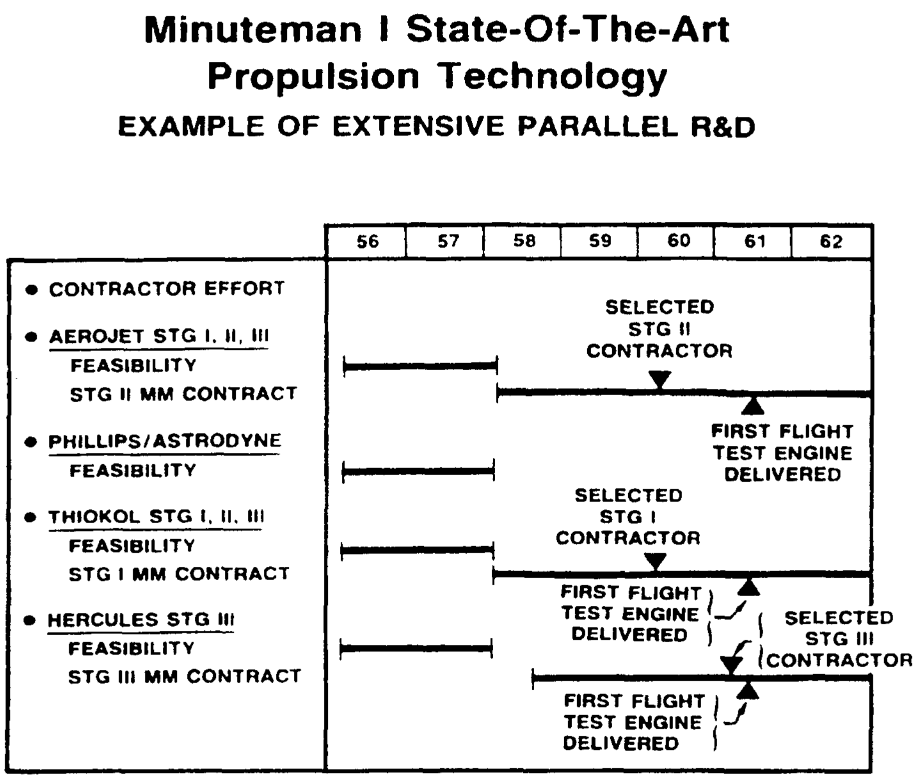
The extended parallel R&D present in the Minuteman I, Polaris A-1, and ALCM programs greatly reduced the resulting risk associated with the relatively short program schedule length, coupled with the technology development that was necessary.

For example, the Minuteman I program had as many as three different contractors developing missile propulsion stages during the period from 1956 to 1961, as shown in Figure 4 (Anderson). The parallel R&D efforts were maintained until (and in the case of the third stage, after) the program production decision in March 1960.

For Polaris:

> In the launch area, 11 different methods of ejecting a missile from a submerged submarine were said to have been simultaneously considered. Similarly, in the navigation area at least two teams approached the problem of developing an inertial navigation system and several substitute navigation schemes were also explored. (Sapolsky)

In the ALCM program, the engine and INE were well advanced in development prior to initiating the long-range ALCM program in Janu-



Source: Robert C. Anderson, "The Acquisition Process, Minuteman I-MX," TRW, Inc., August 1977, pg. 10.

Figure 4. **Minuteman I State-of-the-Art Propulsion Technology**

ary 1977. Each item had undergone parallel development with two contractors culminating with a selected design prior to beginning FSD. For example, the engine and INE down select to a single development contractor occurred in April 1973 and October 1975, respectively. However, the required ALCM deployment schedule necessitated increasing the production rate for the engine and INE. An identical design dual source production competition strategy was established during FSD for the engine and INE in August 1978 and October 1978, respectively, to meet the ALCM deployment schedule (Conrow, Smith, & Barbour).

Development Phase Flight Tests

Although the Minuteman I, Polaris A-1, and ALCM programs had fast paced schedules, their early flight test programs were not particularly successful, and deployment occurred before the systems were fully mature. (Each system, though, still possessed moderate-to-high operational utility.)

Four of the first 10 Minuteman I flight tests (beginning February 1, 1961) were failures or partial failures. (In addition, the first Minuteman I flight was roughly 11 months after the initial production decision!) Flights of the first five Polaris-configured flight test vehicles (AX series, beginning September 24, 1958) ended in failures. Both the candidate Boeing and General Dynamics long-range ALCMs suffered four early terminations each in their 10 missile FSD flyoff (beginning August 3, 1979 and July 17, 1979, respectively).

Consequently, four or more of the first 10 flight tests were failures or partial failures for each program. In effect, the program managers and cognizant DoD personnel had considerable confidence in each weapon system and protected them from adverse external reactions. Any DoD program today having a success factor of 60 percent in its first 10 flight tests, regardless of its flight test record afterwards, would almost certainly encounter considerable monitoring from external organizations (e.g., the Congress), that might adversely impact program cost, performance, and/or schedule, if not cause program termination.

Summary of Some Common Program Characteristics

At this point, I will summarize some of the key characteristics of the Minuteman I, Polaris A-1, and ALCM programs discussed so far.

First, each was a program of the highest national importance and held a BRICK-BAT DX priority rating. Second, each program was not wholly insulated from externally induced program impacts during the development phase. Similarly, the programs were impacted by service and DoD-level organizational and policy changes. Third, each program had only modest to moderate support until mid-way in the development phase. To a great degree, factors external to the Minuteman I, Polaris, and ALCM program offices led to increased program support. Fourth, while each program received the necessary funding, potential funding shortfalls occurred that produced moderate program turbulence in the short run. In addition, the accelerated program schedules led to moderate development phase cost growth in the Minuteman I and ALCM programs. Fifth, each program required a moderate technology advance across the entire system, with a considerable advance in the state of the art required for only a few subsystems. Each program was the beneficiary of important advances made from prior technology or operational programs. Sixth, the initial thrust/weight ratio associated with engine propulsion, coupled with missile weight, proved to be optimistic. Seventh, parallel R&D and simultaneous exploration of several alternatives were used extensively as risk reduction measures for a number of the key technology areas. Eighth, the development phase flight test pro-

grams were not particularly successful. In today's acquisition environment, this would likely lead to program schedule slippage, if not termination.

CAN THE LESSONS LEARNED BE TRANSFERRED TO OTHER DoD PROGRAMS?

Given the common characteristics of the three programs, I will now briefly discuss whether or not lessons learned from the Minuteman I, Polaris A-1, and ALCM programs can be transferred to other DoD programs.

First, the success of the Minuteman I, Polaris A-1, and ALCM programs was largely due to an unusual convergence of technological opportunities and a consensus on national needs.

The ballistic and cruise missile research programs had already made considerable strides in the technology associated with key subsystems for the Minuteman I, Polaris A-1, and ALCM prior to the FSD (equivalent) program phase. Hence, the underlying technologies needed for these missiles were already on the necessary path to yield viable subsystems.

In addition, there was a clear consensus on national needs associated with the perceived Soviet ballistic missile gap, coupled with the Sputnik program, that assisted both the Minuteman I and Polaris A-1 beginning in late 1957 (Perry).

As noted by Robert Perry, the Minuteman I and Polaris A-1 acceleration decisions were:

> . . . made feasible by the pace of technology—which certainly had been more rapid for ballistic missiles than for weapons contemporary with them. But the decisions probably would not have been made as they were if the Soviet Union had not provided first rate motivation: an unmistakable threat.

Similarly, upgraded Soviet air defenses made the role of a long-range ALCM relatively more important than a short-range ALCM coupled with the B-1A penetrating bomber, that had less extensive stealth characteristics than either ALCM.

The breakthrough that permitted the rapid, extensive deployment of these missiles was far more political than technological. The political consensus permitted virtually unrestricted program funding, although moderate short run funding turbulence did exist, and diminished the influence of program critics.

In effect, the convergence of technological opportunity coupled with a consensus of national needs has rarely existed to the extent that it did

for the Minuteman I, Polaris, and ALCM programs except for the Manhattan project, the Apollo project, and perhaps a few others. These were both fortunate and special programs in a number of ways, and although the technological advances made in each program were noteworthy, the political environment, defined through a consensus of national needs, that existed in each case played a dominant role in the development, deployment, and success of these systems. Without both technological opportunities and a consensus on national needs, it is unlikely that many military programs run with a conventional acquisition strategy can achieve the accelerated (development) schedules typically associated with successful commercial programs.

In some cases, a consensus of service needs may be sufficient, while for other programs, a consensus of DoD, government (including the Congress), or even national needs may be necessary to insure a successful program development and deployment in terms of the required performance and/or schedule.

As Harvey Sapolsky stated in 1972, "Most government undertakings, whether civilian or military, are apparently not the beneficiaries of a convergence between technological opportunities and political consensus."

Second, of the eight common Minuteman I, Polaris A-1, and ALCM program characteristics previously identified, only two are both desirable and somewhat within the control of the government program office director. These include the need for only a moderate average advance in the required technology state of the art and the use of parallel R&D for risk reduction (assuming adequate funding is available).

The other six items previously mentioned either require actions external to the government program office to implement (e.g., receiving a BRICK-BAT DX priority rating and service, DoD-level organizational and policy changes, and receiving necessary funding), or represent actions with potentially undesirable effects to the program (e.g., limited early support, optimistic missile thrust/weight ratio, and a not particularly successful development phase flight test program).

Consequently, applying lessons learned from the Minuteman I, Polaris A-1, and ALCM programs to a new military development program may assist the program to some extent (e.g., parallel R&D for risk reduction if funding is available). However, there is no guarantee that the program will achieve the same degree of success as in the Minuteman I, Polaris A-1, and ALCM programs. The level of success achieved by these programs was to a great extent determined by both necessary technological opportunities and a national consensus of needs, which were external to the government program offices and even the DoD itself.

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An Acquisition Process For the Management of Nontechnical Risks Associated With Software Development

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The ability to quantify risk is essential to the processes of budgeting and scheduling. During the process of hiring to complete specified tasks, customers must be able to verify contractor estimates and to make sound judgments on the risks of cost overruns and time delays. The following questions are central to this paper: Do developers with little experience overestimate or underestimate the complexity of the task because of their experience, the assumptions they make, the models they select, and how they define the model limits? What are the sources of risk associated

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with project cost estimation? How can such risk be quantified? This article proposes a systematic acquisition process aimed at assessing and managing the risks of cost overruns and time delays associated with software development. We propose an acquisition process of four phases grounded on three basic premises: (a) Any single-value estimate of cost or completion time is inadequate to capture and represent the variability and uncertainty associated with cost and schedule. Probabilistic quantification is advocated, using, in this paper, the fractile method and triangular distribution. (b) The common expected value, when used as a measure of risk, is inadequate; further, if used as the sole measure of risk, it may lead to inaccurate results. The conditional expected value of risk of extreme events is adopted to supplement and complement the common unconditional expected value. (c) Probing the sources of risks and uncertainties associated with cost overruns and time delays in software development is essential for the ultimate management of technical and nontechnical risks. This article is based on a technical report published by the Software Engineering Institute (Haimes and Chittister, 1993).

PREFACE

The software development community has not been able to agree upon a set of measures to define the basic building blocks that can be used to generate cost and schedule estimates. For example, in most other engineering fields, cost estimates are based on basic measures. Examples include BTUs, PSIs, length of experience, complexity of the requirements, software language to be used, and estimated number of lines of code. The relationships among these factors and the cost or schedule estimate are not always clear, and this raises some questions as to the validity of the estimates in any particular case.

The following quotations excerpted from Innovative Contracting Practices: Transportation Research Circular No. 386, published by the National Research Council (December 1991) highlight the current dismal state of contracting practices:

- Innovative contracting techniques have been developed more in foreign countries than in the United States.
- Unfortunately, the lowest initial cost may not result in the lowest overall cost.
- In fact, current contracting practices provide little incentive for industry to be innovative.

- Agencies should develop contractor responsibility tests that reflect quality and performance factors; these tests should be examined and possible modifications developed.

- Indeed, the ability to assess quality and performance are directly related to the ability to assess risk.

- From a Summary of Questionnaire Findings:
  This [pre-bid conferences] concept was the most popular, receiving a positive response from more than 85% of the states participating in the survey. Better understanding of the scope of work, reduction in unanticipated construction conflicts, plan revisions, and other value engineering benefits can result from such conferences. Specialty jobs, especially fast-track projects, are most appropriate for this process.

- Risk management and assurance. End-result specifications and a determination of QA enter into this issue. Although not currently being practiced, many agencies are considering this concept for future application.

The questionnaire indicated that innovation has intensified in selected topic areas. Many agencies are implementing quality assurance-quality control (QA-QC) philosophies, contractor surveying, value engineering, off-peak time incentives, alternative bidding on structures, and other concepts. Additionally, cost-saving and profitable concepts are being considered for future use and further development. On the other hand, many agencies expressed interest in receiving guidelines on other concepts that were less understood.

INTRODUCTION

Three major classes of likely adverse consequences are prevalent in software development: risk of cost overrun, risk of time delay in the completion schedule, and risk of not meeting performance specifications. Here risk is defined as a measure of the probability and severity of adverse effects (Lowrance 1976). The first two risks, cost overrun and time delay, are nontechnical risks and the third, performance specifications, is software technical risk; more precise definitions are found in Chittister and Haimes (1993). The focus of this paper is on the quantification (assessment) and management of software nontechnical risks, such as cost overruns and time delays.

The more central the role that software plays in overall system inte-

gration and coordination, the more likely the impact of delivery delay and/or of major cost overruns. A series of auditing studies conducted by the General Accounting Office (GAO) in 1992 reveal almost an across-the-board epidemic of cost overruns and time delays in meeting completion schedules associated with software development for selected government-sponsored projects. A case in point is the C-17 aircraft, cited in the previously mentioned GAO report, which experienced a major cost overrun and delivery delay.

In spite of the efforts made by some of the Source Selection Authorities (SSAs) and by their respective boards in selecting contractors, the Department of Defense (DoD) has still had serious software delays. Indeed, an SSA conducts a thorough search, examining, among other factors, the organizational capabilities of the contractor by evaluating performance history. In some cases a set of Key Practice Areas (KPAs) are examined, such as the processes of formal cost estimation and program management, as well as metrics for evaluating various performance criteria.

The Software Engineering Institute (SEI) at Carnegie Mellon University has also developed a methodology known as Software Capability Evaluation (SCE) that (Humphrey & Sweet 1987) used to assess the software engineering capability of contractors. The SCE seeks to answer the question: Can the organization build the product correctly? It does so by considering three separate aspects of the contractor's expertise:

- organization and resource management;
- the software engineering process and its management; and
- available tools and technology.

Another tool, a risk taxonomy, also developed at SEI, addresses the sources of software technical risk and attempts to answer the question: "Is the organization building the right product?" (Carr et al. 1993). The SCE and the taxonomy, then, offer methods of assessing organizational processes and software technical risks; this article presents, on the other hand, a process for quantifying the risks of project cost and schedule overruns.

OVERVIEW OF THE CONCEPTUAL FRAMEWORK

In this article, we present a methodological framework for selecting a contractor that can assist the customer in minimizing the risks of project cost overruns and schedule delays. Although factors other than the selection of contractor(s) may decisively affect software technical and non-

technical risks, they are treated here only as a general background. See Chittister and Haimes (1993, 1994) for a more in-depth discussion of these factors.

The process of selecting contractors is by itself quite complex. The process is driven by legal, organizational, technical, financial, and other considerations—all of which serve as sources of risk. Because the world within which software engineering developed is nondeterministic and the central tendency measure of random events conceals vital and critical information about these random events, special attention is focused on the variance of these events and on their extremes. Two approaches—the fractile method and triangular distribution—are adopted here to quantify the probabilities of project cost overrun and delay in completion schedule. To capture the range of variation and the extremes of these probabilities, conditional expected values of extreme events are calculated using the partitioned multiobjective risk method (PMRM) (Asbeck & Haimes 1984) to supplement the common expected value of software nontechnical risk. To accomplish this objective, the fractile method, triangular distribution, and the PMRM are introduced. Examples are included to clarify the appropriate application of these methods and to demonstrate their utility.

Figure 1 represents the thinking of the methodological framework. The framework can be viewed with four major phases. The purpose of Phase I is to quantify the variances in the contractor's cost and schedule estimates by constructing probability density functions (PDFs) through triangular distributions, the fractile method, or through any other methods that seem suitable to the contractor. Extreme events are assessed from these PDFs. In Phase II, using the SEI Taxonomy, interviews, and the PMRM, the sources of risks and uncertainties associated with each contractor are probed and evaluated. The assumptions and premises, which provide the basis for generating the variances in the contractor's estimates, are identified and evaluated; and the conditional expected value of risk of extreme cost overruns and time delays are constructed and evaluated. Phase III analyzes, ranks, filters, and compares the significance, interpretation, and validity of each contractor's assumptions and premises. And the probabilities of technical and nontechnical risks are assessed. In executing Phase III, three tools and methodologies are used: (1) independent verification and validation team; (2) the risk ranking and filtering method; and (3) comparative analysis. In the final phase, Phase IV, conclusions are drawn on the basis of all the previously generated evidence, including the opinions of expert judgment. The ultimate objective of the methodological approach is to minimize the following three objectives or indices of performance:

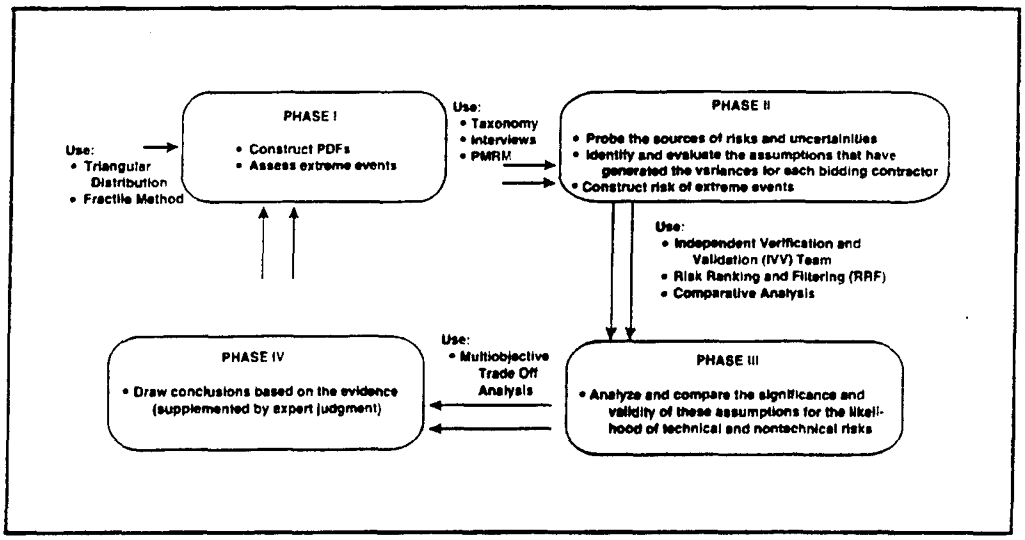

Figure 1. **Proposed Acquisition Process**

$$\text{Minimize} \quad \begin{Bmatrix} \text{risk of project cost overrun;} \\ \text{risk of project completion time delay;} \\ \text{risk of not meeting performance criteria.} \end{Bmatrix}$$

Clearly, multiobjective trade-off analysis, using for example, the surrogate worth trade-off (SWT) method, needs to be conducted where all costs and risks are kept and trade off in their units.

The objective of this article is to develop scientifically sound and pragmatic answers to some of the lingering problems and questions concerning assessment and management of risks of cost overruns and time delays associated with software engineering development.

It is constructive to discuss the four-phase acquisition process in more detail:

1. Phase I will be demonstrated through the construction of the probability density functions (using the fractile method and triangular distribution) and through the assessment of extreme events (using the partitioned multiobjective risk method) by calculating the conditional expected value of extreme events to supplement the common unconditional expected value of cost overrun.

2. Phase II, through the use of the Taxonomy-Based Questionnaire, interviews, and the quantification of risk of extreme events, provides a mechanism to probe the sources of risks and uncertainties, identify and evaluate the assumptions that have generated the variances for each bidding contractor, and construct the conditional

expected value of risk of extreme events, f4(•). The following discussion will focus on probing the sources of extreme events and the contractor's attitude:

Extreme Events — The shape of the probability density function, and particularly the behavior of the tail of the distribution, markedly influence the conditional expected value of extreme events. To demonstrate the effect of the tail of the distribution on projected cost overruns or time delays, all three examples have at least one project cost estimate with a long tail (i.e., a major cost overrun albeit with a relatively low probability).

Most customers are concerned with major cost overruns and time delays of any magnitude. In other words, most customers want to prevent disastrous events that are beyond point b in Figure 2. The region to the left of b (cost overruns that would not exceed 10-15%) is commonly represented by the expected value measure of risk, f5(•), whereas the region to the right of b is captured by the conditional expected value of risk of extreme events, f4(•). With the help of the Taxonomy-Based Questionnaire we can probe the sources of uncertainties and variabilities leading to f5(•) and f4(•). Indeed, the ultimate efficacy of risk assessment is its management through early identification, quantification, and prevention. Such a probe provides insights into the contractor's assumptions about what can go wrong in a severe way that might cause the risk

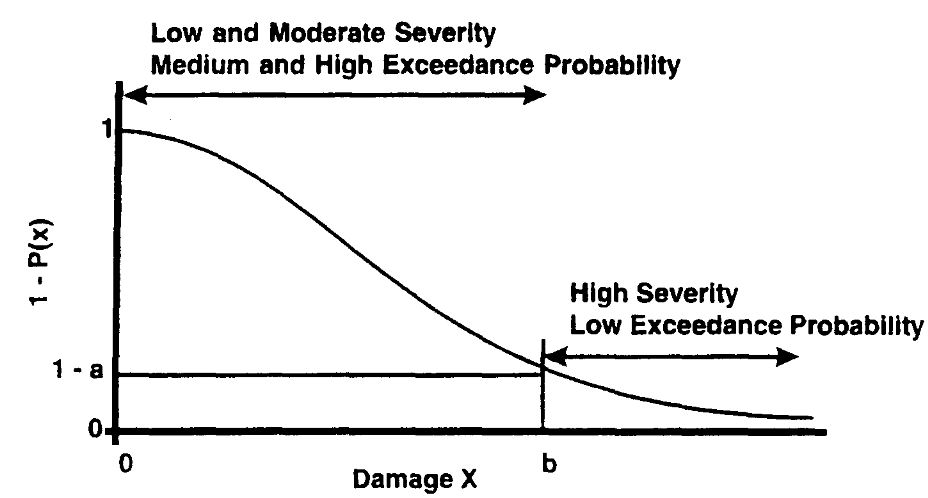

Figure 2. **Mapping the Probability Partitioning Onto the Damage Axis**

of extreme cost overrun or time delay to be catastrophic.

Contractor's Attitude — The Taxonomy-Based Questionnaire, along with the measurements of risk of cost overruns and time delays through the conditional expected value of risk of extreme events and the unconditional (common) expected value of risk should explain not only the contractor's technical, financial, and other managerial assumptions and premises, but also the contractor's attitude toward risk. When a contractor's projection of lowest, most likely, and highest project costs falls, for example, in a close range, there are several possible explanations:

1. The contractor is a risk seeker (a risk-averse contractor would have projected a much wider spread in the lowest, highest, and most likely project cost).

2. The contractor is very knowledgeable and thus has confidence in the tight projections.

3. The contractor is ignorant of the major technical details and complexity of the project's specifications; thus, inherent uncertainties and variabilities associated with the project have been overlooked. Otherwise, the contractor would have projected a wider spread between the most likely and highest cost projections.

The Taxonomy not only constitutes an important instrument with which to discover the reasons for the uncertainties and variabilities associated with the contractor's projections, it also provides a mechanism that allows the customer to assess the validity and soundness of the contractor's assumptions. Indeed, the Taxonomy-Based Questionnaire, which is systematic, structured, and repeatable, is an invaluable process with which the customer can elicit answers to the reasons for the contractors' variabilities. The accumulated assumptions on each contractor are then compared and analyzed.

In Phase III, an analysis and comparison of the significance and validity of the contractor's assumptions about technical and nontechnical risks is conducted. This is accomplished by an Independent Verification and Validation (IVV) team, the Risk Ranking and Filtering (RRF) method, and other comparative analysis methods. In comparing assumptions, a number of issues must be addressed: stability and precedence of the requirements; need for research about solutions; politics and stability of funding; overall knowledge or the lack thereof; level of experience of key personnel; maturity of technology; and maturity of the organization.

In making these comparisons, the customer will look at the reasons for the assumptions and whether they are based on knowledge or naiveté, and whether the contractor has a conservative/risk-averse or liberal/risk-seeking attitude. These issues are highlighted in the example problem in subsequent discussions. Contractor A is projecting a 50% cost overrun as the worst case, while Contractor B is projecting "only" a 40% cost overrun as the worst case. Is Contractor A more knowledgeable or more conservative than Contractor B? Or does the reason for this difference lie elsewhere? Is Contractor A risk-averse whle Contractor B is risk seeking? The information generated by the IVV team, the RRF method, and through other comparative analysis tools will be subjected to the expert judgment of the customer's team, leading to Phase IV of the proposed acquisition process.

Phase IV is the completion step where conclusions are drawn based on the accumulated evidence. Expert judgment is used in conjunction with multiobjective trade-off analysis methods, such as the surrogate worth trade-off (SWT) method (Haimes & Hall 1974). Adopting the systemic proposed acquisition process should markedly reduce the likelihood of major and catastrophic technical and nontechnical risks.

CRITICAL FACTORS THAT AFFECT SOFTWARE NONTECHNICAL RISK

The proposed methodological framework for the quantification and management of software nontechnical risk—the risk of cost overrun and

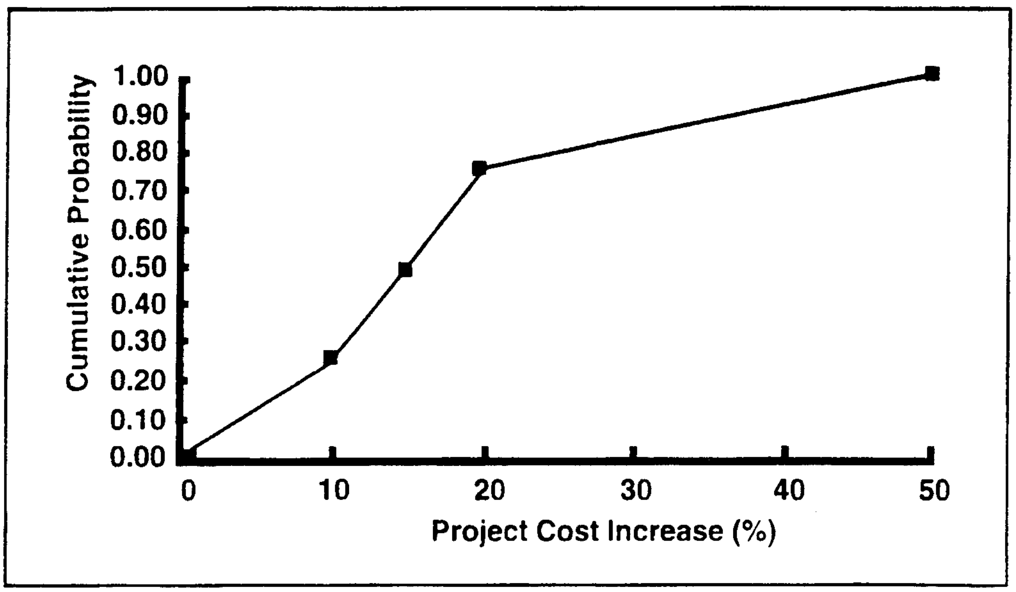

Figure 3. **Graphical CDF for Project Cost Increase for Contractor A**

time delay associated with software development—is grounded on the premise that such management must be holistically based. A holistic approach requires complete accounting of all important and relevant forces that drive the dynamics of cost overrun and time delay. Although a holistic view is advocated, introduced, and discussed in this article, only limited aspects are ultimately quantified. Indeed, only a series of articles would do justice to the quantification of risks associated with all factors that embody software nontechnical risk. By their nature, quantification and management of software nontechnical risk (and to a large extent software technical risk) involve the customer and the shadow client (the U.S. Congress, in the case of DoD) and the contractor(s). Organizational interface between the customer and the contractor(s), the state of technology and know-how, the complexity of the specification requirements, add-on modifications and refinements, the availability of appropriate resources, and the models used for project cost estimation and schedule projections are major considerations.

Since each element is in itself a complex entity with diverse dimensions, it is essential to recognize which characteristics of each component contribute to software nontechnical risk. Only by understanding the sources of risk can it ultimately be prevented and managed.

The Customer

The term customer is a misnomer because it connotes a singular entity. Yet, in most large-scale software engineering systems, such as DoD systems, projects are initiated, advocated, nourished, and supported by multiple constituencies with some common, but often different, goals and objectives. Furthermore, for DoD projects, there is also the shadow customer—the U.S. Congress, itself influenced by various lobbyists, power brokers, and stakeholders. The existence and influence of this multiplicity of clients on the ultimate resources for the development of software engineering constitute a critical source of software risk. It is not uncommon for a pressure group to affect either the design specifications and/or the resources allocated for a specific DoD project, and thus to have an impact on its final cost and its completion time. The "organizational maturity" level of the client is another factor that influences software nontechnical risk. A client that possesses internal capabilities to communicate with the contractor(s) on both the technical and nontechnical levels is more likely to have a better understanding and therefore management of software nontechnical risk. This attribute will become more evident in this article as specific quantitative information on the variances of cost and schedule is solicited in the proposed methodological framework.

The Contractor(s)
Elaborate procedures and protocols describing contractor selection for the development of software engineering have been designed and are being employed by government agencies and corporations. A commonly accepted axiomatic premise is that the organizational maturity level of the contractor and the experience, expertise, and qualifications of its staff markedly affect the management of software technical and nontechnical risks.

The Interface Between the Customer and the Contractor(s)
One of the dominant factors in initiating both technical and nontechnical risks can be traced to the organizational interface between the customer and the contractor(s). Adequate and appropriate communication between the two parties, and the understanding and the appreciation of each other's role throughout the life cycle of the software development process are imperatives to the prevention and/or control of potential risks.

The State of Technology and Know-how
Although many consider the contractor's access to knowledge and the access to appropriate technology to be major factors in controlling software technical risk, these factors also impact software nontechnical risk. In particular, the lack of access to appropriate technology or a deficient know-how in the contractor's staff is likely to cause a measurable time delay in the completion of a project and is also likely to cause cost overrun.

The Complexity of the Specification Requirements
The more unprecedented the client's project specifications in terms of advanced and emerging technology, the higher the risk of time delay in its completion and of its cost overrun. Most systems developed by the DoD are advancing the state of the art in some field of technology, e.g., software development, stealth, propulsion, and satellites. The requirements in these fields are necessarily complex since the parameters are constrained by the task and are frequently subject to modifications because of changing technology.

The Add-on Modifications and Refinements
Add-on modifications and refinements are viewed by many as an Achilles' heel in terms of software nontechnical risk. Although these add-on modifications are often associated with software nontechnical risk, they also constitute a critical source of software technical risk. This is because not all modifications are appropriately related to and checked

against the original design to ensure ultimate compatibility and harmony. Very large and complex systems are difficult to manage. Systems are now developed by multiple companies, each having its own area of expertise, and changes often ripple through the entire system. A wide range of factors may cause mid-course modifications; however, three categories of causes emerge from this range:

a. Threat or Need Change: When a new threat is projected or a new need is contemplated.

b. Improved New Technology: When a new technology provides improved performance or quality, such as a new sensor.

c. Obsolete Technology Replacement: When the pre-selected technology becomes obsolete before the contract has even begun or been completed.

The Availability of Appropriate Resources

One open secret in government procurement and occasionally in the private sector is the level of pre-allocated funds for a specific project. The competitive zeal of contractors often outweighs the technical judgment of their professional staff; the outcome is a bid that is close to the pre-allocated funds by the client even though it is clear to the bidder that the job with its specification requirements cannot be delivered at that level of funding. This not-uncommon phenomenon is dramatically illustrated in numerous documented examples by Hedrick Smith (1988).

> The standard technique is to get a project started by having the prime contractor give a low initial cost estimate to make it seem affordable and wait to add fancy electronics and other gadgets much later through engineering "change orders," which jack up the price and the profits. Anyone who has been through building or remodeling a house knows the problem. "This is called the buy-in game," an experienced Senate defense staff specialist confided.

The Models Used for Project Cost Estimation and Schedule Projection

A number of models are used to estimate project cost and its completion schedule. Constructive Cost Model (COCOMO) (Boehm 1981) and Program Evaluation and Review Technique (PERT) are representative examples. Models can be potent tools when they are well understood,

are supported by an appropriate database, and adhere to the assumptions upon which they are designed to operate. The complexities of such models, however, often result in their misuse and/or invalid interpretations of their results. They thereby ironically become a source of software nontechnical risk. The successful application of the proposed methodological framework, however, does not depend on the specific model used by either the contractor or the customer to estimate either the cost or the schedule.

From the above it seems that the sources that contribute to software nontechnical risk are organizational and technical in nature; they stem from failures associated with the contractor as well as the customer. In terms of the contractor, these failures primarily originate from and are functions of such elements as:

a. the organizational maturity level;

b. the process and procedures followed in the assessment of the project's cost and schedule;

c. the level of honesty exhibited by management in communicating the real cost and schedule to the customer (and of course vice versa);

d. the extent and level of new and unprecedented technology imposed on the project;

e. the level of experience and expertise of the staff engineers in software engineering in general and in the application domain in particular;

f. the level of experience and expertise of the management team in software engineering;

g. the overall competence of the team developing the software;

h. financial and competitive considerations;

i. immature technology, methods, and tools;

j. the use of technology in new domains;

k. new combinations of methods and tools in new ways and their use in a new software development environment;

l. requirement modifications causing changes in the system's architecture.

In terms of the customer, the natures of organizational failures partially overlap those of the contractor's, but also have distinctive characteristics:

a. the process and procedures followed in the assessment of the project cost and schedule;

b. the level of specificity at which the system and software requirements are detailed;

c. the number of changes and modifications requested by the customer during the software development process (changes which generally introduce many new errors) are often not harmonious with earlier specification requirements;

d. the commitment of project management (associated with the customer's organization) to closely monitor and oversee the software development process;

e. the specific requirements for technology, e.g., specific compiler, data base management systems;

f. the level of honesty exhibited by management in communicating the real cost to the "real client" (e.g., the Department of Defense as a client and the U.S. Congress as the "real client").

BASIS FOR VARIANCES IN COST ESTIMATION

Most, if not all, developers of large complex software systems use cost models to estimate their costs. These models are based on a set of relationships based on such parameters as the size and complexity of the software, the experience level of the software developer, and the type of application within which the software will be used. Different models generate different weights or levels of importance for these parameters, and not all models use the same parameters. Therefore, one cost model can lead to a radically different cost estimate than another just on the basis of which parameters are used in the model and how they are implemented. Even if the parameters are used consistently, however, different developers will probably not agree on the value or weight of the parameter in the first place. Many organizations, in fact, consider

their interpretations of these parameters to contribute to their "competitive edge" because the definition affects their ability to determine costs accurately. For example, an organization that has experience in developing space system software may not have the same perception of difficulty when developing a complex avionics software system as would an organization that has significant experience in that area. Their understanding of space systems, however, will alter their definition of the avionics system parameters. Do developers with little experience overestimate or underestimate the complexity of the task because of how they define these parameters? As stated in the beginning, these are questions central to this paper: What are the sources of risk associated with project cost estimation? How can such risk be quantified?

Although creating, maintaining, and updating project cost estimation metrics and parameters are extremely important for an organization, it is nevertheless unlikely that a future project will be similar enough to previous projects to merit directly importing these metrics or parameters; such metrics and parameters may not be directly applicable without appropriate modifications. Indeed, cost estimators are required to (and do) use judgment when applying these parameters to a new project requirement. Furthermore, cost estimation constitutes a critical area with regard to the sources of risk for software development, which is without parallel to other fields. For example, if a contractor was estimating the cost to construct a building with 50 stories, yet had previously only built structures with a maximum of 10 stories, the contractor would not just increase the estimate five-fold. The contractor would question the basic foundations and relevance of extending the 10-story model to the new structure parameters. However, in software, it is not uncommon to increase estimates for new projects by a factor of five from previous projects of one-fifth the size and complexity. Many new systems have size estimates of over 1,000,000 lines of code even though the developers have little experience with systems of this size.

Another example is in the use of commercial off-the-shelf (COTS) software. The original assumption that a commercial database management system (DBMS) can be used to meet customer requirements may change if the customer requires features not supported by DBMS suppliers. Such changes may have serious ramifications for the cost estimate depending on how the developer plans to solve the problem. If the developer chooses to subcontract out the effort and deal with the subcontractor in a way similar to dealing with the DBMS vendor, this has ramifications for the risk associated with the subcontractor—an important subject that will be discussed later. The alternative is for the developer to undertake the development of his or her own DBMS. This

requires an additional set of assumptions, design parameters, and judgments regarding the architecture, size, experience level, domain knowledge, software engineering knowledge, and support environment needed to develop the DBMS. Each of these assumptions, parameters, and judgments has some uncertainty associated with it. This uncertainty contributes to the overall risk in the cost estimate. If the developer chooses to subcontract the DBMS development to an outside vendor, then the issue for the contractor is to understand and account for the set of assumptions that are made by the subcontractors on the DBMS and on the system architecture.

The ability of the developer to make valid assumptions and design decisions is usually based on a set of metrics; these metrics can either be based on current measurements or on past performance. Either way, there has to be an agreed-upon set of measures that is being evaluated (such as the number of lines of code needed to accomplish specified tasks or productivity rates in terms of lines of code per hour). The difficulty with software development is that the community has not agreed upon basic measures, such as how to count lines of code or how to measure productivity. Also, the difficulty with using performance history is that the systems under development are sufficiently different so that the history may not adequately reflect the new parameters accurately.

THE QUANTIFICATION OF SOFTWARE NONTECHNICAL RISK AND THE EVALUATION OF VARIANCES

The premise of this article is that the manner in which the customer selects a contractor affects the risk of cost overruns, time delays, and failure to meet performance specifications. Therefore, the proposed methodological approach requires the contractor to provide the customer with more than fixed, deterministic values for the cost and time schedule to deliver software with prespecified performance requirements.

Building on quantitative probabilistic assessment, the contractor is asked to submit either an estimated variance of the cost and time to completion, or a probability density function (Figure 4) for the projected project cost and time schedule. (A similar approach can be adopted to quantify software technical risk.) This variance may be generated from, for example, a triangular distribution, where the contractor specifies the lowest possible cost, the highest possible cost, and the most likely cost of the project. Alternatively, the contractor may choose to provide the variance estimate through the fractile method. (The construction of a PDF using a triangular distribution and the fractile method will be subsequently discussed.) Similar estimates are to be provided for the completion schedule. *The information provided by the contractor con-*

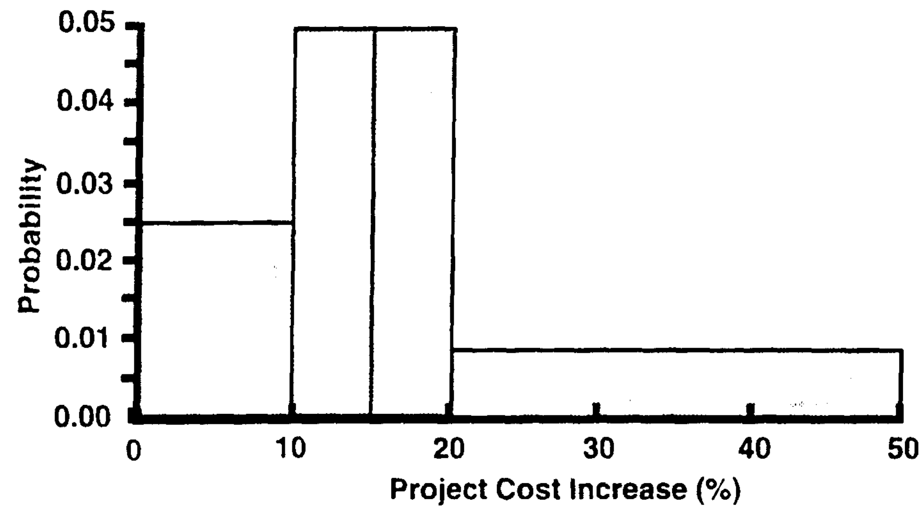

Figure 4. **Probability Density Function for Project Cost Increase for Contractor A**

stitutes the basis for the generation of probability density functions (PDFs) associated with the project's cost and its completion time. Assuming that the customer (with the assistance of a MITRE-type organization, if needed) is also capable of providing (for comparative purposes with the clients' variances) basic variance information, which allows the generation of the customer's PDFs for the projected cost and completion time, then the following method will be useful. A mechanism is developed here that enables the customer to compare various contractors' probabilistic estimates of several attributes and characteristics to its own estimate. To use either of the two approaches to estimate cost or schedule variances, the contractor should familiarize the team making such estimation with the intricacy of these approaches and alert it to the cognitive biases inherent in such an estimation process. In their quest to quantify these human biases, Alpert & Raiffa (1982) conducted several experiments over two decades ago and arrived at the conclusion that with appropriate training, the use of the fractile method can be very effective. The question of gaming and the manipulation of the approach by some contractors to gain advantage is discussed under the subhead "Comparative Analysis Among Contractors."

The proposed methodological framework requires a number of steps. First, the customer requires that each bidding contractor submit either basic information on the cost and completion time vari-

ances or the corresponding PDFs. In the latter case, the contractor may choose to use a triangular distribution, the fractile method, or any other means that the contractor believes will provide the most accurate estimate. Clearly, the contractor can and is likely to use models and other tools to generate the required PDFs. At the same time the customer's staff will generate its own PDFs for cost and completion time. The customer is now able to compare not only the expected values (the means) of each contractor's cost and completion time, but also the variances of these estimates. Furthermore, a comparison of the extremes of each PDF provides valuable information to the customer about each contractor's capabilities and compatibility. Although some of the efficacious attributes of the methodological framework will be better understood after we introduce the section on "Risk of Extreme Events" and the example problems, an overview of the required steps may clarify the process:

1. Use the fractile method, the triangular distribution, or any other approach to quantify the variances associated with project cost estimates and the completion schedule.

2. Assess the contractor's capability to deliver the product and to estimate the likely variance of the project's cost and schedule through SEI's Software Risk Taxonomy-Based Questionnaire. The SEI taxonomy and the accompanying questionnaire provide a framework for identifying the technical uncertainties in a project and the root causes of these uncertainties. It also provides a method for assessing the honesty and credibility of the contractor's analysis and figures.

3. Evaluate, in a quantitative way, any discrepancy between the variance assessments of the contractor and the customer. (The quantification is likely to lead to significant information about the likelihood of extreme events and their potential consequences for the entire project.)

4. Investigate and understand the contractor's assumptions in estimating variances. This information will enable the customer's staff to take appropriate measures to mitigate software nontechnical risk.

5. Integrate the information on the contractor derived from (a) the quantitative variances received on the projected cost and completion schedule with (b) the results generated from the Software Risk Taxonomy-Based Questionnaire.

6. Use the risk ranking and filtering (RRF) method to rank the risks associated with each prospective contracting organization; then, compare those risks against one another and against an established norm.

Although these methods and processes may not provide an optimal approach for selecting the best or most valid estimate, they do provide a foundation that is systematic and repeatable to allow the evaluators to gain significant knowledge and insight into the estimators' assumptions. This insight is critical from two perspectives; it enables the customer to:

- evaluate whether the contractors' estimates and assumptions are valid and consistent with the specifications; and
- establish a foundation by which to evaluate and judge future changes to cost and schedule estimates.

These methods and processes also provide a mechanism for the customer's evaluation team to document the assumptions and risks in a cost or schedule estimate, identify the root issues associated with these assumptions and risks, and organize this information within the taxonomy framework. This information can then be used to measure progress and can also be used as a metric against future cost and schedule estimates.

RISK OF EXTREME EVENTS

In general, the estimates of the most likely project cost provided by the dominant number of contractors will be within a close range of one another. Since assessing and ultimately preventing potential major cost overruns and time delays are of major concern in this paper, our interest here is in what can go wrong in the extremes, i.e., in the behavior of the tail of the distribution. This can best be captured through the conditional expected value of extreme events. The conditional expected value of risk, denoted by $f_4(\bullet)$ (which will be defined later), can provide valuable information that supplements and complements the average cost or most likely cost estimates.

Most analysts, who use probabilistic quantitative methods to measure the risk of project cost overruns and delays in the completion schedule, resort to the most common mathematical construct for the quantification of risk—the expected value of risk. Whether the probabilities associated with the universe of events are viewed by the analyst as discrete or continuous, the expected value of risk is an operation that essentially

multiplies each event by its probability of occurrence and sums (or integrates) all these products over the entire universe of events. This operation literally commensurates adverse events of high consequences and low probabilities of exceedance with events of low consequences and high probabilities of exceedance. Indeed, the expected value masks the extremes and hides the effects of less likely outcomes.

The misuse, misinterpretation, and fallacy of the expected value, when it is used as the sole criterion for risk in decision making, are discussed elsewhere (Haimes & Chittister 1993, Asbeck & Haimes 1984). Many experts are becoming convinced of the grave limitations of the traditional and commonly used expected-value concept and so are augmenting the expected value of risk with a supplementary measure—the conditional expectation—by which decisions about extreme and catastrophic events are not averaged out with more commonly occurring high-frequency/low-consequence events.

The partitioned multiobjective risk method (PMRM) is a risk analysis method developed for solving probabilistic multiobjective problems with a focus on extreme events (Asbeck & Haimes, 1984). Instead of using the traditional expected value of risk, the PMRM generates a number of conditional expected-value functions, known as risk functions, which represent the risk given that the damage falls witin specific ranges of the probability of exceedance or within a range of adverse consequences (generically termed as damages). Before the PMRM was developed, problems with at least one random variable were solved by computing and minimizing the unconditional expectation of the random variable representing the specific damage. In contrast, the PMRM isolates a number of damage ranges (by specifying partitioning probabilities) and generates conditional expectations of damage given that the damage falls within a particular range. In this manner, the PMRM can generate a number of risk functions, one for each range, which are then augmented with the original optimization problem as new objective functions. In this paper the discussion will be limited to one conditional expected value of extreme events, denoted by f4(•).

The conditional expectations of a problem are found by partitioning the problem's probability axis and mapping these partitions onto the damage axis. The damage axis in this case can be project cost overrun in terms of dollars or percentage of overage above the contracted level; alternatively, the damage can represent time delay in terms of months or weeks or in terms of percentages in relation to the original time schedule. Consequently, the damage axis is partitioned into corresponding ranges. *A conditional expectation is defined as the expected value of a random variable given that this value lies within some prespecified prob-*

ability range (or within some prespecified damage range). Clearly, the values of conditional expectations are dependent on where the probability axis (or the damage axis) is partitioned. The choice of where to partition is made subjectively by the analyst in response to the extreme characteristics of the decision-making problem.

A continuous random variable X of damages (e.g., cost overrun or time delay) has a cumulative distribution function (CDF) P(x), and a probability density function (PDF) p(x), which are defined by the relationships

$$\text{CDF: } P(x) = \text{prob}[X \leq x] \tag{1}$$

and

$$\text{PDF: } p(x) = \frac{dP(x)}{dx} \tag{2}$$

The CDF represents the nonexceedance probability of x. The exceedance probability of x is defined as the probability that X is observed to be greater than x and is equal to one minus the CDF evaluated at x.

The expected value, average, or mean value of the random variable X is defined as

$$E[X] = \int_0^\infty p(x)\, dx \tag{3}$$

For the purpose of this article, a modified version of the PMRM is presented to simplify the mathematical discussion and to focus the analysis on the conditional risk of extreme events. Let 1 - a, where $0 < a < 1$, denote an exceedance probability that partitions the domain of X into two ranges. On a plot of exceedance probability, there is a unique damage b on the damage axis that corresponds to the exceedance probability 1 - a on the probability axis. Damages (e.g., cost overruns or time delays in project completion schedule) less than b are considered to be of low to moderate severity; damages greater than b are of high severity. The partitioning of risk into two severity ranges is illustrated in Figure 2. If the partitioning probability a is specified, for example, to be 0.95, then b is the 95th percentile.

The conditional expected damage (given that the damage is within that particular range) provides a measure of the risk associated with the range. The measure of conditional expected value of risk of interest here is that of low exceedance probability and high severity, denoted by

$f4(\bullet)$. High severity may mean a high cost overrun or a high time delay in the project's scheduled completion. The function $f4(\bullet)$ is the expected value of X, given that x is greater than or equal to b:

$$f4(\bullet) = E[X \mid x \geq b] \tag{4}$$

For any probability of exceedance, one can generate the traditional, unconditional (common) expected value of risk (of cost overrun and/or of time delay) denoted by $f5(\bullet)$, and the conditional expected value of risk of extreme events (of same) denoted by $f4(\bullet)$. Note that

$$f4(\bullet) = \frac{\int_b^\infty x\, p(x)\, dx}{\int_b^\infty p(x)\, dx} \tag{5}$$

$$f5(\bullet) = \int_0^\infty p(x)\, dx \tag{6}$$

where p(x) is the probability density function.

EXAMPLE PROBLEM

DoD is considering the introduction of a new strategic airplane that will constitute the flagship of the Air Force as we enter the third millennium. Aware of the powershift from hardware to software in technology and the emerging centrality of software as the overall system integrator and coordinator, DoD considers the development of software for this airplane to be of paramount importance (Chittister & Haimes 1994). The Air Force commissions the assistance of a support organization to develop, in collaboration with its own staff, specifications and a request for proposal (RFP) for designing, prototyping, and developing the software needed for the flagship airplane. Following a detailed and tedious process of qualifying prospective bidders, the Air Force issues an RFP for the development of the required software engineering. This time, however, the RFP includes items that had not been requested previously. For example, the RFP requires that each contractor provide variances along with the estimated project's cost and completion schedule, instead of the commonly-practiced requirement of single deterministic values. The RFP leaves it up to the contractors to determine the form

that these variances take, including, if the contractor so desires, the type of PDF selected for each estimate. The Air Force and its support team, planning to use the same approach themselves in evaluating the various proposals, recommends in the RFP the optional use of the fractile method or the triangular distribution when complete statistical information is not readily available.

To capture the mathematical details entailed in the process of developing representative probability density functions (PDFs) for cost and completion time, a step-by-step procedure using the fractile method (adopted by Contractors A and B) is presented here. For pedagogical purposes, a detailed analysis is presented for Contractor A only. Similar analysis should be followed for Contractor B and the customer. The team from Contractor A estimates a most likely cost of $150 million. After considerable brainstorming sessions, the following information emerges:

- Best case project cost increase = 0% (i.e., project cost is $150 million);

- Worst case project cost increase = 50% (i.e., project cost increase is $75 million, for a total of $225 million);;

- Median value of project cost increase (equal likelihood of being greater or less than this value) = 15% (i.e., project cost increase is $22.5 million, for a total of $172.5 million);

- 50-50 chance that the actual project cost would be within 5% of the 15% median estimate (i.e., project cost increase is (15 ± 5)%).

From the above information, the following fractiles (percentiles) are readily determined.

- The best scenario of no cost overrun (0% cost increase, i.e., a total cost of $150 million) represents the 0.00 fractile (0 percentile);

- The worst scenario of 50% cost overrun (a total cost of $225 million) represents the 1.00 fractile (100th percentile);

- The median value of 15% cost overrun (a total cost of $172.5 million) represents the 0.50 fractile (50th percentile);

- The 0.25 fractile (25th percentile) is (15-5)% = 10% increase over $150 million (a total cost of $165 million).

- The 0.75 fractile (75th percentile) is (15+5)% = 20% increase over $150 million (a total cost of $180 million).

The above assessment of project cost for contractor A and similarly for Contractor B and for the customer is summarized in Table 1 and is used as a basis for constructing the corresponding cumulative distribution function (CDF) for Contractor A. (See Figure 3.)

The CDF (Figure 3) can now be represented in terms of a PDF (Figure 4). To construct the PDF, one must be guided by the following principles:

(a) The area under the shaded area (the PDF) must be equal to 1.

(b) The first quartile in Figure 3 (representing 25% of the probabilities) spans a cost overrun from 0% to 10%. Thus, the corresponding area of the PDF (Figure 4) must be equal to one-fourth of the total area, i.e., 0.25. Dividing 0.25 by 10 yields a height of 0.025 for the first rectangle in Figure 4. Similarly for the other three quartiles, each of the second and third quartiles spans 5% of project cost increase. Thus, the height of the rectangle of the PDF (Figure 4) is 0.25 on the probability axis and when divided by 5 yields a height of 0.05 on the probability axis. Finally, the last quartile spans a cost overrun of 30% (from 20% to 50%). Thus, the height of the rectangle (on the probability axis) is 0.25 divided by 30 which yields a height of 0.008. Figure 5 depicts the exceedance probability (1-CDF) vs. project cost increase. To focus on the exceedance probability of a major cost overrun, say between 20% and 50%, only that part of Figure 5 is depicted in Figure 6. Note that by just using basic rules from geometry, one can relate the exceedance probability to any project cost increase x, for 20% _ x _ 50%.

The expected value of the percentage of project cost increase, f5(•), can be determined from geometry (Figure 4):

$$f5(\bullet) = 0.25\ [\ 0 + \frac{(10 - 0)}{2}\ ] + 0.25\ [10 + \frac{(15 - 10)}{2}] + 0.25\ [15 + \frac{(20 - 15)}{2}]$$

$$+\ 0.25\ [20 + \frac{(50 - 20)}{2}]$$

$$= 0.25\ (5) + 0.25\ (12.5) + 0.25\ (17.5) + 0.25\ (35)$$

$$= 0.25\ (70) = 17.5\%\ \text{(i.e., total cost of \$(150 + 26.25) million)}$$

The expected value of the percentage of project cost increase may also be calculated using Equation 3. Note that the expected value of cost overrun of $26.25 million (i.e., total cost of $176.25 million) for Contractor A does not provide any vital information on the probable extreme behavior of project cost. Also note that there is a one-to-one functional relationship between the probability axis and the percentage of project cost increase as is depicted in Figure 5. For example, there is 0.1 probability (one chance in 10) that project cost increase will be equal to or above 38%. This result is generated as follows (here we are interested in the probability of exceedance of 0.1, i.e., $\alpha = 0.90$, or $(1-\alpha) = 0.10$):

$$\frac{x - 20}{50 - 20} = \frac{ab}{ac} = \frac{0.25 - (1 - \alpha)}{0.25}$$

$$\text{Thus,} \quad x = 30 - \frac{30(1 - \alpha)}{0.25} + 20 = 38\% \quad \text{for } \alpha = 0.9$$

Alternatively, we can compute from Figure 6 the partition point x (the percentage of increase in cost) that corresponds to a probability of 0.1 as shown below:

$$(1 - \alpha) = (50 - x)\, h$$

where h is the height in the probability axis

$$h = \frac{0.25}{50 - 20} = 0.0083$$

$$x = 50 - \left(\frac{1 - \alpha}{h}\right) = 50 - \frac{(1 - 0.9)}{0.0083} = 38\% \quad \text{for } \alpha = 0.9$$

The conditional expected value of project cost can be calculated for a couple of scenarios to shed light on the behavior of the tail of the PDF. For example, given (from Figures 5 and 6) that there is 0.1 probability of project cost overrun that would be equal to or exceed 38% of its original scheduled budget, management might be interested in answering the following question: What is the conditional expected value of extreme cost overrun beyond the 38% (or extreme cost overrun with exceedance probability that is below 0.1)? Or posed differently, within the range of exceedance probabilities between 0.1 and 0.0 and range of cost overruns between 38% and 50%, what is the expected value of project cost overrun? Note that (a) the maximum cost overrun was predicted not to exceed 50%; (b) the conditional expected value is the common expected value limited between specific levels of cost overruns instead of the entire range of possible cost overruns; and (c) the ex-

pected value is a weighted average of possible cost overruns multiplied by their corresponding probabilities of occurence and summed over that entire range.

Using Equation 3, the common, unconditional expected value of cost overrun, f5(•), was calculated earlier to be 17.5%. Similarly, the conditional expected value of cost overrun under the scenario of 0.1 probability of exceeding the original cost estimate (by 38% or by $57 million) computed using equation 5 yields f4(•) = 44%. Note that the PDF of cost overrun portion from 20% and beyond is a linear function. Alternatively, the conditional expected value can be computed as the mean of the shaded area in Figure 7.

$$f4(\bullet) = 38 + \frac{(50 - 38)}{2} = 44\%$$

In other words, the adjusted (conditional) expected value of cost overrun, when it is in the range of 38% to 50% of the original scheduled cost, is 44%.

Unless the project is a cost-plus contract, the interpretation of these results should alarm top management of Contractor A; although the expected cost overrun of the proposed budget is 17.50% above the budgeted cost of $150 million, there is a 10% chance (0.1 probability) that the cost overrun will exceed 38% of the budgeted cost! Furthermore, at

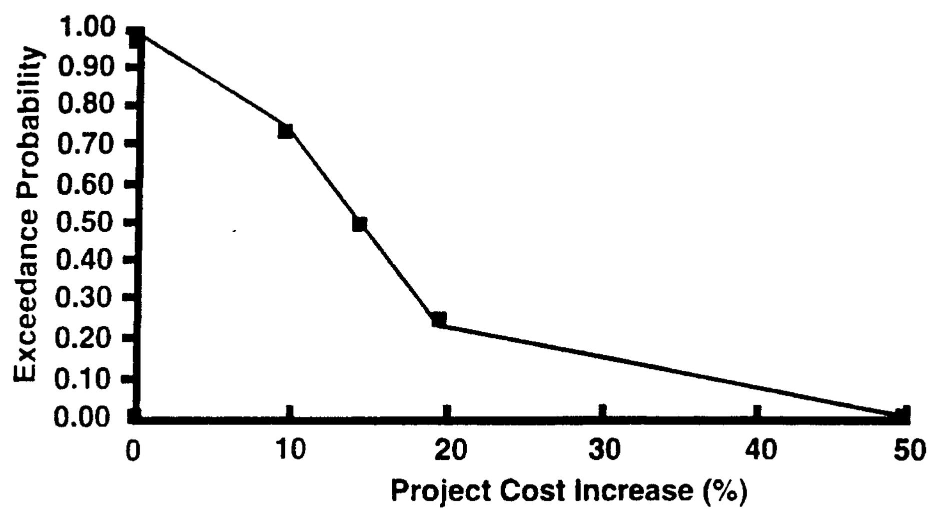

Figure 5. **Exceedance Probability For Project Cost Increase for Contractor A**

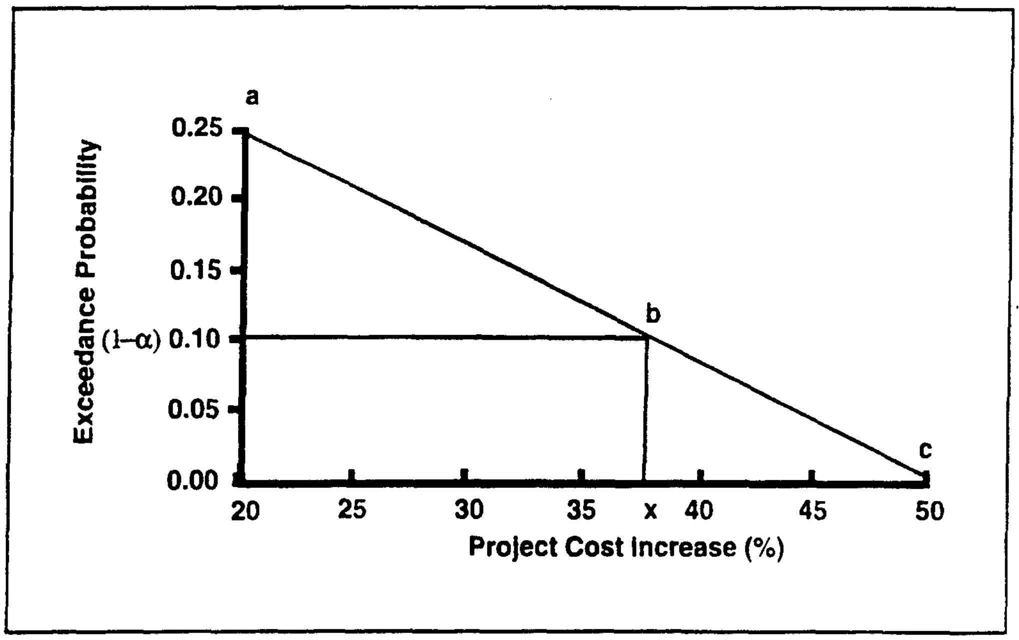

Figure 6. **Computing the Partition Point on the Damage Axis for Contractor A**

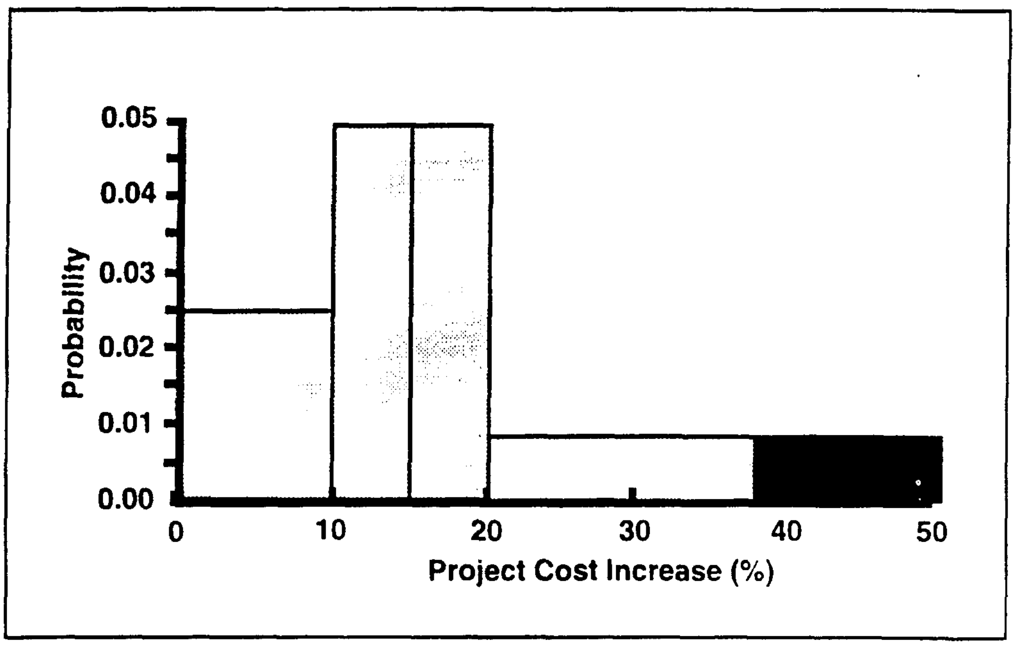

Figure 7. **Computing the Conditional Expected Value for Contractor A**

a 10% chance of cost overrun, the conditional expected value of cost overrun that exceeds 38% is 44% above the original budget, i.e., an exceedance of \$66 million; in other words, under these conditions, the conditional expected value of the total cost will be (\$150 + 66) million = \$216 million.

It is worthwhile to clarify at this point the meaning of the two distinct terms of cost overrun: 38% and 44%. The term 38% cost overrun corresponds to a single probability point and is derived directly from Figure 6. The term 44%, on the other hand, represents the conditional expected value, the averaging of all the probabilities from 0.10 to zero multiplied by the corresponding cost overruns from 38% to 50%, summed as appropriate and scaled. Thus

$$f4(\bullet) = E\,[X \mid \geq 38\% \text{ cost overrun}] = 44\%$$

or equivalently,

$$f4(\bullet) = E\,[X \mid \geq \$207 \text{ million}] = \$66 \text{ million}$$

It is constructive to further clarify the information summarized in Table 2. Consider the customer's column. According to the customer's estimates the common, unconditional expected value of cost overrun is 11.25%. Through mathematical calculations on the basis of the information provided by the customer (as shown in Table 1), it can be determined that there is 0.1 probability of project cost overrun that would exceed 24% of its original scheduled cost (see Haimes and Chittister 1993). Thus, the conditional expected value of extreme cost overrun between 24% and 30% (or extreme cost overrun with exceedance probability that is below 0.1) is 27%.

COMPARATIVE ANALYSIS AMONG CONTRACTORS

An important activity within Phase III of the four-phase acquisition process is understanding the reasons and the genesis for the variations of the estimates among the contractors and explaining these differences on the basis of the evidence collected through the Taxonomy, the interviews, and other ways.

1. The contractor knows what is to be known about the project.

2. The contractor does not know what is to be known about the project.

Table 1.
COMPARATIVE TABULAR CDF

Fractile	Project Cost Increase (%)		
	Customer	Contractor A	Contractor B
0.00	0	0	0
0.25	5	10	15
0.50	10	15	20
0.75	15	20	25
1.00	30	50	40

3. The contractor knows and is aware of the unknowns and uncertainties about the project.

4. The contractor does not know and is not aware of the uncertainties surrounding the project.

Of course this knowledge or the lack thereof is not absolute and the contractor's own knowledge may be at various levels between complete awareness and complete ignorance. This discussion assumes that no gaming is taking place. Safeguards must be developed, however, to secure against a contractor who opts to game the system.

With these and other comparisons that can be made as desired, the customer's ability to assess the various risks and thus to mitigate and manage them is greatly enhanced. For example, when there appears to be a substantial discrepancy either between the customer's and one of the contractor's estimates or among the estimates of the various contractors, the customer can inquire (if legally permissible) about evidence and sources of these variations; otherwise, the customer can draw conclusions on the contractor's estimation capabilities and honesty. The use of SEI's software Risk Taxonomy-Based Questionnaire [SEI 1993] in conjunction with these analyses will be discussed in a subsequent section.

Table 2.
SUMMARY OF RESULTS

	Customer	Contractor A	Contractor B
Unconditional Expected Value, f5(•)	11.25%	17.50%	20%
Partitioning Point	$\alpha = 0.90$	$\alpha = 0.90$	$\alpha = 0.90$
Corresponding Percent of Cost Increase	x = 24%	x = 38%	x = 34%
Conditional Expected Value, f4(•)	27%	44%	37%

The methodology advocated in this paper does not embrace an adversarial relationship between the customer and the prospective contractors. Project cost overrun and schedule time delay are not assumed to happen necessarily because of contractors' conspiracy or malice. Rather, the premise here is that often the customer and the contractors do not adhere to a systemic risk assessment approach in their evaluation and projection of software nontechnical risk, and the unintended result is a cost overrun or delay in project completion schedule.

The use of the Software Risk Taxonomy-Based Questionnaire developed by the Software Engineering Institute constitutes the basis for this needed systemic risk assessment approach (Carr et al. 1993). The SEI taxonomy questionnaire is divided into three major parts: Product Engineering, Development Environment, and Program Constraints.

The primary focus of the SEI's risk identification process is to elicit known and unknown risks from the personnel associated with the project, e.g., administrative and technical management, development engineers, proposal team, and cost estimators. The identification process consists of a taxonomy-based questionnaire and a method for conducting interviews using this questionnaire. This enables the interviewers to probe

for both technical and nontechnical risks that affect the project. The information that is gathered from the interviews can be grouped and ordered using a set of criteria and a risk ranking and filtering method. The strength of this approach is that the process is repeatable and systematic, and it enables the analysis and comparison of data from multiple organizations. The analysis and comparison of risks and concerns coupled with the extreme events information will provide the customer with a foundation upon which to make more informed decisions regarding the risks in the cost or schedule estimates.

An additional benefit of the analysis is that customers can gain valuable insight into the contractors' assumptions and the depth of their understanding regarding the requirements and technology associated with the project.

CONCLUSION

Controlling the cost and time schedule of major projects has been and continues to be a major problem facing government and non-government acquisition managers. Software development projects are no exception. Because of the close influence and interaction between software technical and nontechnical risks and the diverse sources and causes that constitute the driving force behind these risks, the acquisition manager's job is complicated. One of the major premises of this paper is that a careful, systemic, and analytically-based process for contractor selection is imperative for the prevention of major risks of cost overruns and time delays. This paper proposes such an acquisition process. The four-phase process can be best viewed as a framework rather than as a rigid step-by-step procedure. The obvious limitation in the scope of any single paper prevents a full demonstration of each of the four phases of the proposed acquisition process. The three sample problems should successfully communicate to the reader the mathematical mechanics associated with Phase I and the construction of the measure of risk of extreme events in Phase II. The readers who are more familiar with the SEI Taxonomy-Based Questionnaire will be able to relate more easily to its use in Phases II and III. Similar statements can be made on the familiarity with the risk ranking and filtering method, the independent verification and validation team, and with other methods used in the proposed acquisition process. As a framework, the discussion in this paper must be construed by the reader as the beginning of a dialogue toward the quantification and management of the risks of cost overruns and time delays associated with software development. In this spirit, we consider this paper to be a precursor which will be followed by others in the future. The expected benefits that result from the prevention of

major and extreme risks, combined with the low expected cost of early mitigation strategies, encourage us to believe that this area is worthy of much further consideration.

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Using Earned Value for Performance Measurement on Software Development Projects

Major David S. Christensen and Daniel V. Ferens

The earned value method is an internationally recognized project managment tool for measuring progress on projects. Despite its popularity, it has not been widely applied on software development projects. This paper proposes the use of earned value on software development projects. After a brief description of the earned value method, seven software metrics appropriate for earned value application are described. The use of these metrics should facilitate more effective management of software development projects.

INTRODUCTION

Measuring progress on software development projects is a difficult but important challenge for project managers. In the Department of De-

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fense (DoD), computer software costs are a substantial and growing portion of the budget. In 1993, for example, DoD software development costs are estimated at over $30 billion (Defense Systems Management College [DSMC], 1990). Similar trends are apparent in high-tech commercial projects.

Since 1967, the DoD has used a performance measurement technique known as "earned value" to monitor performance on defense contracts. In the DoD, the earned value method is usually implemented with Cost/Schedule Control Systems Criteria (C/SCSC). However, the method does not require C/SCSC. As a result, earned value is rapidly becoming an internationally recognized tool in project management, with both defense and nondefense applications.

Despite the established utility of the earned value method, its use on software development projects has not been widespread. Based on discussions with DoD project managers and analysts, software development progress is often assumed to be unmeasurable, and software projects are classified as "level-of-effort." Given the relative importance and cost of these projects, arbitrarily classifying them as "level-of-effort" is extremely unfortunate.

This paper proposes the use of the earned value method to measure progress on software development projects. After a brief description of the earned value method and related topics, seven software metrics are described and evaluated for their appropriate application in a performance measurement system that is based on the earned value method.

BACKGROUND

Performance Reporting and C/SCSC

To facilitate the effective cost management of defense acquisitions, the DoD requires standardized cost management reports from defense contractors. Two reports that specifically focus on cost and schedule performance are the *Cost Performance Report* (CPR) and the *Cost/Schedule Status Report* (C/SSR). The CPR is normally submitted on contracts which require compliance with the Department of Defense Cost/Schedule Control Systems Criteria (C/SCSC). For contracts not required to comply with C/SCSC, the C/SSR is usually required.

Compliance with the C/SCSC is required on "significant" contracts and subcontracts within all acquisition programs, including those that require software development. DoD Instruction 5000.2 defines significant contracts as research, development, test, and evaluation contracts with an estimated cost of $60 million or more (in fiscal year 1990 constant dollars), or procurement contracts with an estimated cost of $250 million or more (in fiscal year 1990 constant dollars). For contracts

below these thresholds, compliance with C/SCSC may also be required when contract risk is judged to be high. Compliance with C/SCSC on firm fixed price contracts is not normally required (Department of Defense [DoD], 1991, February).

Cost/Schedule Control Systems Criteria are not a management system imposed by the government on the contractor. Instead, the criteria establish minimal standards for the contractor's existing planning, scheduling, budgeting, accounting, and analysis systems, collectively termed the contractor's "internal management control systems." In total, there are 35 rather generic standards. One criterion, for example, requires a comprehensive budget for all the authorized work on the contract. Another criterion requires that all the authorized work be scheduled.

The DoD specifies two objectives for the criteria: (a) for contractors to use effective internal cost and schedule management control systems; and (b) for the government to be able to rely on timely and verifiable data produced by those systems for determining product-oriented contract status (Department of the Air Force [DAF], 1989, October). Implicit in these objectives is the assumption that if the contractor's management control systems comply with the criteria, then the data generated by those systems are reliable.

The cost management report summarizes the contract's cost and schedule performance using the key data elements shown in Figure 1. The Budgeted Cost of Work Scheduled (BCWS) is the sum of budgets allocated to time-phased elements of work on the contract, known as work packages. The cumulative expression of these budgets, termed the "Performance Measurement Baseline," takes on a characteristic S-shaped curve. The end point of the baseline, termed the "Budget at Completion" (BAC), represents the total budget of all the identified work on the contract.

Another key data element is the Budgeted Cost of Work Performed (BCWP). BCWP, also known as "earned value," is the same number as BCWS. They are both the budgeted cost of work. The only difference is when they are recorded. BCWS is recorded when work is planned to be completed; BCWP is recorded when work is actually completed. If work is completed at a different time from when it was planned to be completed, then a "schedule variance" is identified. Figure 1, for example, illustrates an adverse schedule variance because cumulative BCWS exceeds cumulative BCWP. When all of the work on the contract is completed, cumulative BCWP will equal cumulative BCWS.

Figure 1 illustrates two other variances: cost variance and variance at completion. A cost variance is the difference between BCWP and Actual Cost of Work Performed (ACWP). In this example, the cost vari-

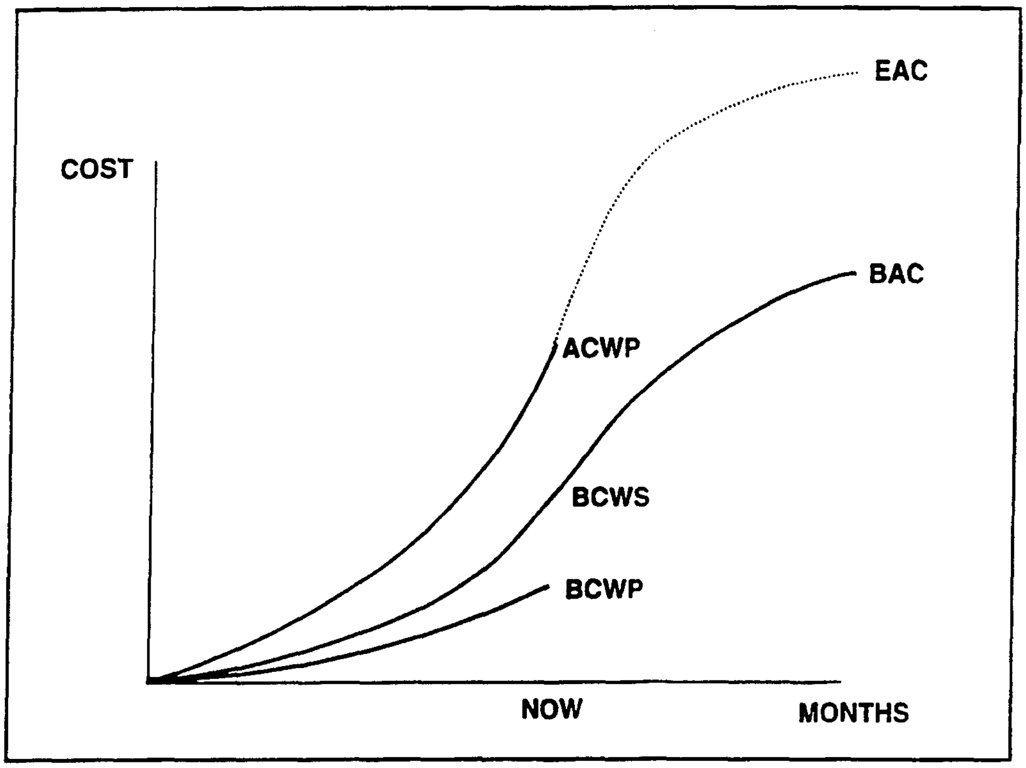


Figure 1. **The Performance Measurement Baseline (PMB)**

ance is unfavorable because the actual cost exceeds the budgeted cost of the completed work. The variance at completion is the difference between the Estimate at Completion (EAC) and the Budget At Completion (BAC).

The EAC is simply the actual cost of completed work plus an estimate of the cost to complete the remaining work on the contract. This estimate is reported by the contractor on the cost management report and reviewed for reasonableness by the government. When this projected final cost exceeds the budget, the contractor is effectively predicting an overrun, termed an adverse "variance at completion." Figure 1 illustrates the usual condition of a defense acquisition contract: behind schedule and overrunning the budget (Christensen, Antolini, and McKinney, 1992).

The C/SCSC require that all "significant" variances on the contract be analyzed. By definition, a significant variance is one that breaches a threshold (DAF, 1987, October, pps. 3-17). Thresholds are usually expressed as a percentage and in dollars. If, for example, a threshold for a work package was ±10 percent and $10,000 dollars, then any variance that breached thiss threshold would be investigated and it is to be hoped, corrected. The intent is that though disciplined variance analysis, prob-

lems can be corrected before they become serious.

Clearly, for variance analysis to be effective, the proper planning and measurement of earned value is essential. One of the purposes of the criteria (C/SCSC) is to assure that the earned value method is properly planned and implemented. Earned value (BCWP) is the key number on the cost management report. If it is inaccurate, then the three variances and the EAC are also wrong. It is possible, however, to use the earned value method without the criteria. When this is the case, controls similar to those described by the criteria should be enforced. Otherwise, BCWP will not be a reliable indicator of progress on the project. This paper will now describe how BCWP is planned and measured.

Planning and Measuring Earned Value

As described earlier, the criteria require that all the work on a contract be budgeted and scheduled. To accomplish this, the contractor will first develop a product-oriented family tree of hardware, software and services that successively subdivides all of the authorized work on the contract. This detailed breakdown of the work, termed the "Contract Work Breakdown Structure" (CWBS), typically extends to levels where work is to be performed, called "work packages." There may be over 100,000 work packages on a large defense acquisition contract.

A work package has three characteristics: technical content, schedule, and budget. Once the contract is subdivided into work packages, each work package is arranged in the order that it has to be accomplished, assigned start and stop dates, and assigned a budget. The budget for each work package is then spread through the life of the work package according to the technical requirements of the work. These "time-phased" budgets for all work packages become the basis for monthly BCWS, monthly BCWP, and the Performance Measurement Baseline. The proper time-phasing of the budget is thus critical to the planning of BCWS and the subsequent measurement of BCWP.

There are many "earned value methods" to time-phase the budget for BCWS and BCWP (Fleming, 1992, pps. 119-127). As indicated in Table 1, earned value methods depend upon the nature of the work that is being measured. Progress on the contract should ideally be measured by assessing discrete tasks which have a specific end product or end result. Work of this kind is termed "discrete effort." Common earned value methods appropriate for discrete effort include weighted milestones, interim milestones, and percent complete.

Work that can be directly related to other identified discrete tasks, such as quality control or inspection, is termed "apportioned effort." Support type activities, such as sustaining engineering or coordination,

TABLE 1
EARNED VALUE METHODS

Category of Work	Earned Value Method
Discrete Effort	Weighted Milestones (e.g., 50-50)
	Interim Milestones
	Percent Complete
Apportioned Effort	"Factored" on Discrete Effort
Level of Effort	BCWP set equal to BCWS

that does not result in a final end product is termed "level of effort" (LOE). On criteria-compliant contracts, these categories are mutually exclusive and collectively exhaustive. All work must be classified into one of these categories.

Although the criteria allow the contractor to use any one or any combination of these earned value methods, there are some general requirements. These requirements are intended to insure the usefulness of the performance measurement data.

To be useful for performance measurement, the data must be verifiable and objective. Therefore, the contractor must document the earned value method used in developing BCWS before the work begins, and then use the same method for measuring BCWP when work is being performed. Because BCWS and BCWP are the same number, it's absolutely essential that the same method be used for each. In addition, allowing one method for BCWS and another for BCWP would allow the contractor to distort performance measurement and the variances reported on the cost management report.

In addition to being verifiable and objective, the numbers for BCWP must be valid; namely, BCWP must clearly reflect performance. Therefore, the use of arbitrary measurement methods, such as the weighted milestone method, are limited to short-span work packages. An example of an arbitrary weighted milestone method is the "50-50" method, where one half of the budget for the work is "earned" (recorded as BCWP) when the work begins, and the other half is earned when the work is completed. To minimize the distortion created by such an arbitrary performance measurement, the method is generally restricted to work packages with durations of two months or less.

For longer work packages, "interim milestones" are required, where a portion of the budget for the work is assigned to each milestone. When that milestone is accomplished, the budget for that milestone is recorded

as BCWP. As long as the milestones are tangible and integral parts of the work, this interim milestone method will properly reflect performance on long-span work packages.

For some work packages, identifying interim milestones may not be possible. In this case, the contractor may simply estimate the percentage of the work planned to be completed for planning BCWS, and later estimate the percentage of work actually completed for recording BCWP. It is to be hoped that the contractor will employ some objective parameter of progress as a basis for estimating the percent complete. In any case, the criteria require that the contractor's method for determining BCWP be rational. The contractor should, therefore, be able to explain the basis for determining the estimates of BCWS and BCWP.

Another requirement related to earned value methods involves the proper matching of ACWP with BCWP. To facilitate the timely analysis of cost variances, ACWP should be recorded in the same period that BCWP is recorded. When BCWP for a work package is recorded but the actual cost is not yet known, ACWP may be estimated. Later, when the actual cost is known, ACWP can be adjusted.

EARNED VALUE AND SOFTWARE DEVELOPMENT

It has been difficult to use earned value methods on software development projects. Models that predict the amount and timing of software development costs, and metrics for accurately measuring work accomplishment have been inadequate. An obvious metric, percentage of code written, is both deficient and misleading. For earned value methods to be effective, BCWS and BCWP must be reflect the timing and technical requirements of the work. Software development involves much more than writing code, and the most difficult coding is often accomplished last. Therefore, using the percentage of code written as an arbitrary method to plan BCWS and record BCWP would not be an appropriate application of the earned value concept.

Fortunately, there are more appropriate methods or metrics for planning and measuring software development costs. Some of these can be used to adequately plan BCWS, and measure BCWP and ACWP. Regardless of the metric, the general approach is to divide the work into portions, establish a schedule and a budget for each portion, and then use this time-phased budget as baseline against which performance is measured.

Figures 2 and 3 illustrate how software projects are planned. Figure 2 represents a typical hierarchical breakdown of a system into hardware configuration items (HWCIs) and computer software configuration items (CSCIs). CSCIs are divided into computer software components (CSCs)

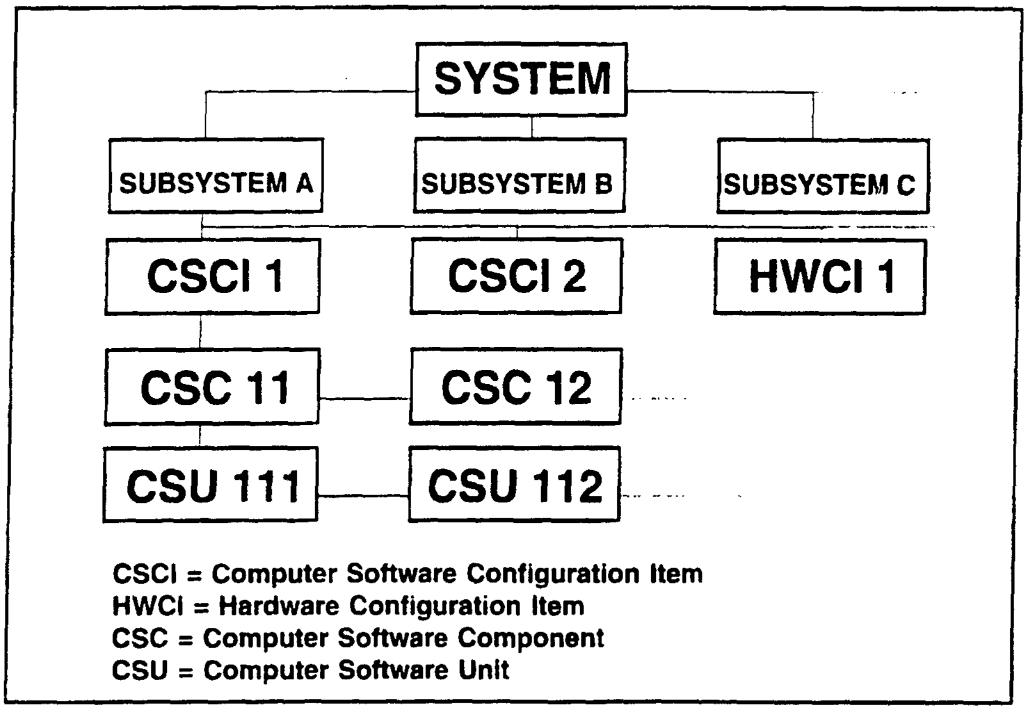


Figure 2. **A System Hierarchy for Software Development**

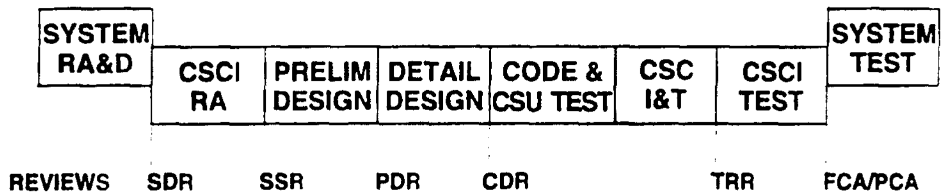
and computer software units (CSUs), which represent the lowest-level subfunctions of the software (DoD, 1988, February). For performance measurement to be meaningful, performance and actual costs should be planned and measured where work is being performed. For software development projects, this should be at the CSCI level or below. At higher levels, the planning of BCWS and the measurement of BCWP and ACWP would require rather arbitrary and subjective estimates of actual progress and costs.

To facilitate the objective measurement of progress and costs, earned value methods typically require the use of work packages. Figure 3 illustrates the typical software development process, known as the "waterfall" model described in DOD Standard 2167A (DoD, 1988, February). Each phase of this process may be considered a work package, appropriate for earned value application. The second through seventh phases are performed at the CSCI level. Coding does not begin until the fifth phase. In the waterfall model, a coded product is not available until CSCI testing is completed; however, the completion of earlier phases is extensively documented and includes reviews and audits to assure adequacy.

Using the phases of software development as work packages for earned value application appears to be a viable approach, especially if the cost and schedule of each phase can be estimated with reasonable accuracy,

SOFTWARE DEVELOPMENT PROCESS

DOD-STD-2167A PHASES AND REVIEWS



PHASES

1. System Requirements Analysis and Design (RA&D)
2. Computer Software Configuration Item (CSCI) Requirements Analysis (RA)
3. Preliminary Design
4. Detailed Design
5. Code and Computer Software Unit (CSU) Testing
6. Computer Software Component (CSC) Integration and Testing (I&T)
7. Computer Software Configuration Item (CSCI) Testing
8. System Testing

REVIEWS

System Design Review (SDR)
Software Specification Review (SSR)
Preliminary Design Review (PDR)
Critical Design Review (CDR)
Test and Readiness Review (TRR)
Functional Configuration Audit (FCA)
Physical Configuration Audit (PCA)

Figure 3. **The Software Development Process**

and appropriate metrics for measuring technical progress and cost within each phase are available. The earned value method generally requires that the cost and schedule for each phase (work package) be estimated. Next, an appropriate metric to measure cost and technical progress is identified and used to develop the time-phased budget (BCWS). Finally, as work is accomplished for that work package, the time-phased budget for the accomplished work is recorded as BCWP and its cost is recorded as ACWP.

Several models are available for predicting the cost and schedule for each phase of a software system or CSCI, including the Constructive Cost Model (COCOMO), PRICE-S, SEER, SLIM, SoftCost-R, and

Checkpoint (Ferens, 1990). Although the accuracies of these models have not been validated for a broad range of programs, they are generally suitable for rough estimates. For a review of the accuracy of these models, see Institute of Electronic and Electrical Engineers (IEEE) (1988).

Once the budget and schedule for each work package have been estimated, software metrics may be used to plan BCWS and measure BCWP and ACWP. Although much research has been performed on software metrics, there is currently very little standardization. Therefore, a manager must determine which metric is appropriate for each phase of the project.

There are several desirable properties of software metrics (Conte, Dunsmore, and Shen, 1986; DeMarco, 1982; Humphrey, 1990; Jones, 1991). To be useful, the metric should be (a) **relevant** to the work being measured; (b) **explicit** (directly measurable); (c) **objective**; (d) **absolute** (able to be assessed without reference to an average); (e) **timely** (available early in the project); and (f) **independent** from the influence of personnel performing the project. Of these, Ayres and Rock (1992) found relevance to the most important property. Accordingly, the metrics appropriate for BCWS, BCWP and ACWP were chosen with this property in mind. The first two metrics are appropriate for earned value measurement, and the third is most appropriate for ACWP. The remaining four metrics are more useful in investigating variances than in the direct measurement of earned value or actual costs. Each metric and its relevance to the earned value approach is now be briefly described. A more detailed description of these metrics is provided elsewhere (Ayres and Rock, 1992; DoD, 1991, February).

1. **Requirements and Design Progress.** This metric is based on the number of CSCI requirements determined during the first two phases of software development. The requirements are detailed in several documents (System/Segment Design Document, Software Requirements Specification, Software Design Document) written during these phases. As illustrated in Figure 4, the planned and actual CSCI requirements are used for determining BCWS and BCWP, respectively. Figure 4 also illustrates that the total CSCI requirements may change. In addition, counting the requirements can be difficult. If these limitations can be overcome, this metric is a viable tool for earned value application, especially early in the project.

2. **Code and Testing Progress.** This metric is based on the number of CSUs that have been designed, coded, and tested. As illustrated in

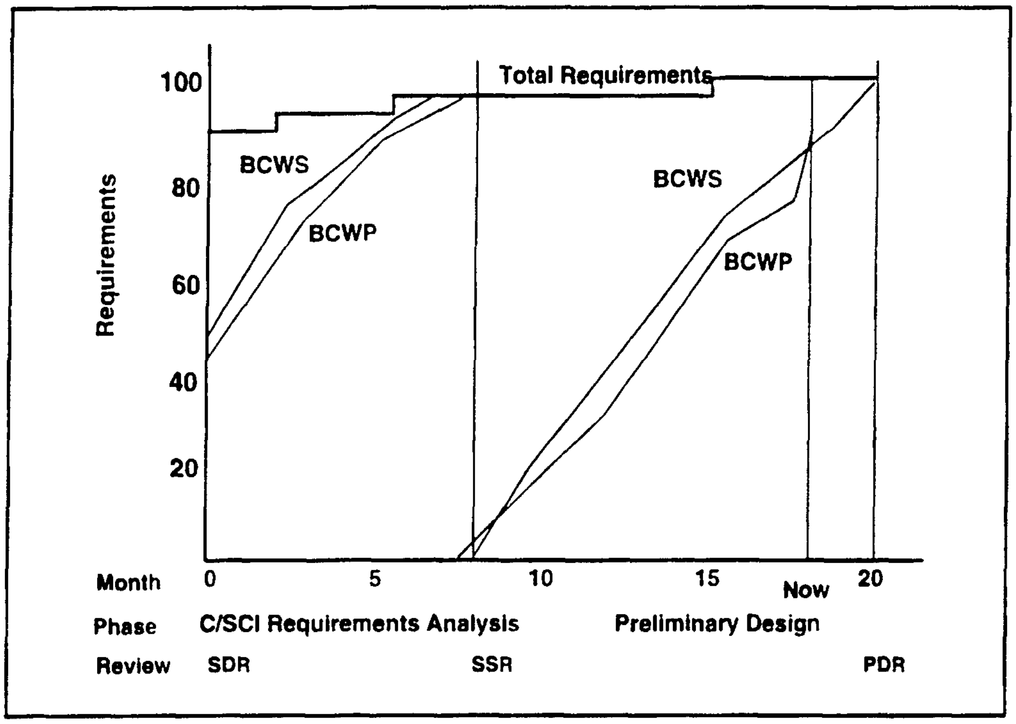


Figure 4. **The Requirements and Design Process Metric**

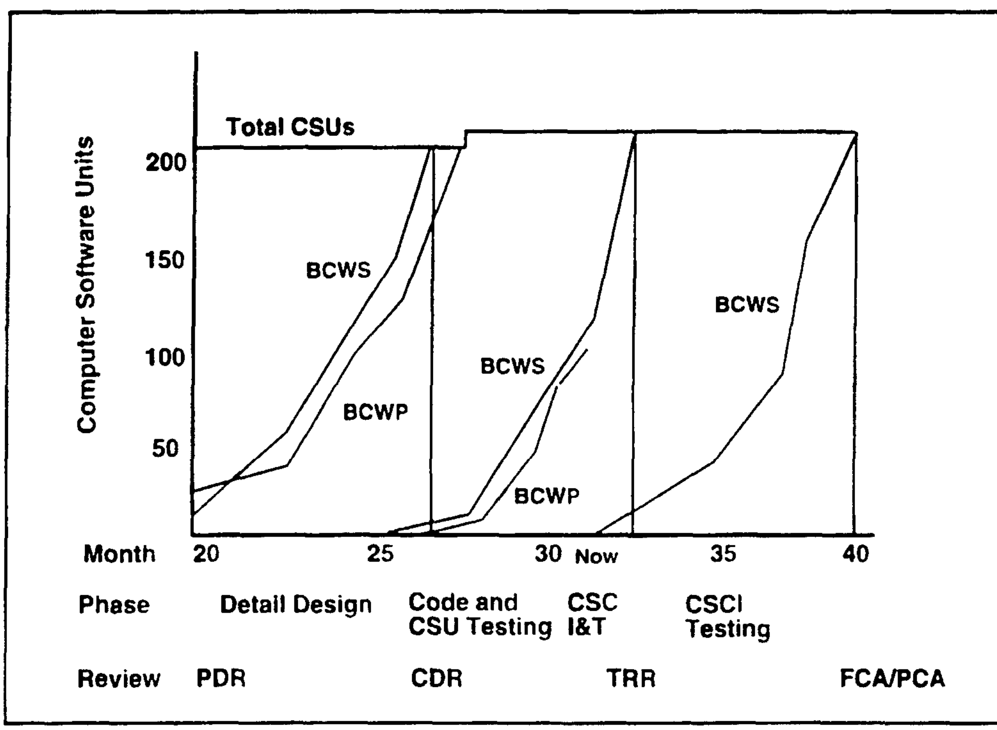


Figure 5. **The Code and Test Progress Metric**

Figure 5, it is appropriate after the second phase of the software development project. Like the previous metric, the planned and actual CSUs represent BCWS and BCWP. In addition, the total number of planned CSUs for each phase represents the end point of the performance measurement baseline for that phase. Generally, this metric is easier to measure than the previous one. CSU progress can be measured using a unit development folder or similar technique. Also, more detailed information is known about the software project in these later phases.

3. **Person-months of Effort**. As illustrated in Figure 6, this metric is based on person-months throughout the project. As such, it is particularly useful for measuring ACWP because the costs of software development are almost entirely labor-related. Using planned person-months for BCWS and BCWP is probably inappropriate because available estimation methods may be inaccurate, and the time spent on the project may not correlate to progress. Nevertheless, this metric is useful, if only because it is the single metric in this collection that directly reflects ACWP.

4. **Software Size**. This metric tracks the size of the software during the entire project. Usually, size is expressed in source lines of code

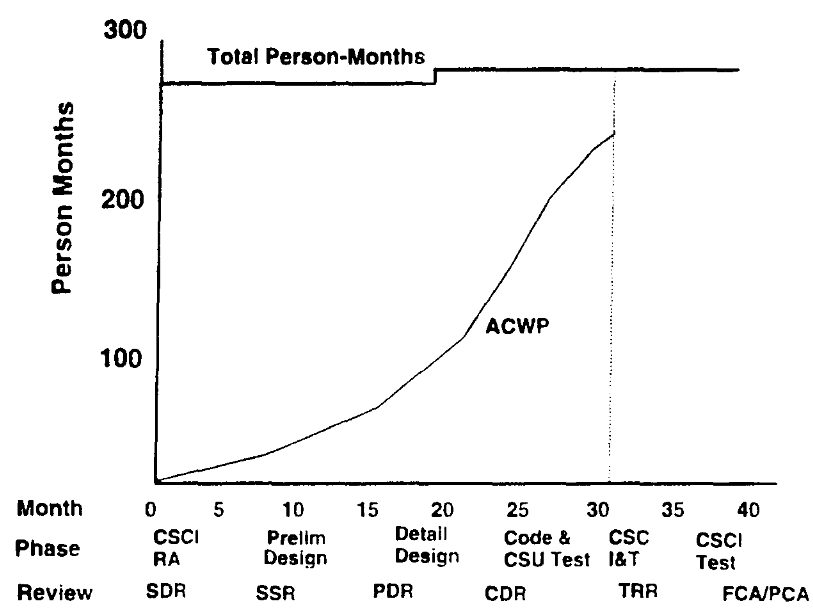


Figure 6. **The Person-Months Progress Metric**

(SLOC). The total size may be divided into categories of new, modified, and reused code. Since there is a direct relationship between size and effort required, this metric may be helpful in estimating actual cost. However, effort required and actual progress may not correlate; accordingly, the method may be inadequate as an earned value metric, and should be used as a technical parameter to investigate the cause of cost variances based on the other metrics.

5. **Computer Resource Utilization**. This metric is a measure of the available computer hardware timing, memory, and input/output (I/O) resources consumed by the software. It is closely related to the software size metric described above in that increases in total size will result in a greater percentage of hardware resources utilized. Like software size, this metric can be helpful early in the program for determining the causes of variances.

6. **Requirements Stability**. This metric has similarities to the requirements and design progress metric. Like that metric, requirements stability tracks total requirements; however, it also tracks the number of changes (additions, deletions, and modifications) made to requirements throughout the entire development process. Numerous or frequent changes will result in additional effort required, and may explain unfavorable cost and schedule variances.

7. **Design Stability**. This metric is like requirements stability in that it tracks the number of changes to the detailed design (CSUs). Like the code and testing progress metric, it is primarily useful later in the program, after preliminary design is completed. Frequent lower-level design changes will result in additional effort required.

CONCLUSION

Table 2 lists the seven metrics described in this paper, and indicates the role that each metric could have in an earned value performance measurement system. The table also indicates our judgment of how well the metric satisfies the seven desirable properties of software metrics. Because these properties are nearly identical to the goals for earned value measurement that are described in C/SCSC, they appear to be viable candidates for earned value application, especially the first three listed in the table.

Of course, the seven metrics described in this paper are not the only ones. Especially worthwhile are "quality metrics" that track defects, com-

Table 2
SOFTWARE METRICS FOR EARNED VALUE APPLICATION

Metric	Desirable Attributes of Software Metrics						Role in Earned Value System	Phase(s) in Software Development Process
	Relevant	Explicit	Objective	Absolute	Timely	Independent		
Requirements and Design Progress	Yes	Yes	Somewhat	Yes	Yes	Somewhat	BCWS and BCWP	CSCI RA and Prelim Design
Code and Test Progress	Yes	Yes	Somewhat	Yes	No	Somewhat	BCWS and BCWP	Detail Design, Code and CSU Testing, CSC I&T, and CSCI Testing
Person-Months Progress	Yes	Somewhat	Yes	Yes	Yes	Somewhat	ACWP	All phases
Program Size	Yes	Somewhat	Yes	Yes	Yes	Somewhat	Technical indicator for variance analysis	All phases
Computer Resource Utilization	Yes	No	Somewhat	Yes	Somewhat	Yes	Technical indicator for variance analysis	All phases
Requirements Stability	Yes	Yes	Yes	Somewhat	Yes	Yes	Technical indicator for variance analysis	All phases
Design Stability	Yes	Yes	Somewhat	Somewhat	No	Yes	Technical indicator for variance analysis	All phases

plexity and modularity (Jones, 1991). While these metrics may not directly relate to earned value measurement, they do help measure quality, which is the *sine qua non* of software projccts today; using them in tandem with the ones recommended for earned value application is highly recommended.

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BOOK REVIEWS

The Balanced Budget

(Malabre, Jr., A. L. (1994), *Lost Prophets — An Insiders History of the Modern Economists*. Boston: Harvard Business School Press; Eisner, R. (1994), *The Misunderstood Economy*. Boston: Harvard Business School Press; Morton, D. (1983) *Making America Work Again*. New York: Crown Publishers; Brewer, J. (1989), *The Sinews of Power*. New York: A. Kopf; Krugman, P. (1994), *Peddling Prosperity*; New York: W.W. Norton & Company, Inc.)

Reviewed by
Franz A. P. Frisch

Every person listening to the evening news or reading the daily newspapers knows that the words Balanced Budget *are buzz words in Washington. Congress is expected to wrestle with these two words for an indeterminate number of years in an effort to make them a reality. The big question is, of course, can it work? Whatever happens program managers need to be aware that the discussions and ultimate actions on Capitol Hill will have an impact on their programs. The reviewer looks at five books that address the* Balanced Budget *concept, comments on the authors' credentials and credibility, and draws on his own experience and background to present a stimulating view of this thought consuming subject.*

Every economic theory is correct . . . sometimes.
Every economic theory is wrong . . . mostly.
–Franz A. P. Frisch

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"Book Reviews" really is not the right heading. This is a "theme review" of five books written without exception by economists of high repute. All deal, at least in one chapter of their book, with the *balanced budget* theme, a subject presently dominating public attention and debate.

The observer of economic events might find highly irritating the way in which leading experts of the same branch can disagree, not only in details, but on fundamental principles and theories. But those disagreements illustrate the nature of economics, a discipline located somewhere between philosophy and science, demonstrating the interplay between abstract ideas of values and concrete measurable facts. Hence, all economic theories are conceptualizations of observations at a given time. Unfortunately, every conceptualization and interpretation needed to arrive at a theory represents the point of view or more generally the value system of the observer and objectivity is just an illusion. The same "facts" can have different meanings for different people; and even the same people may view the facts differently depending on the time and situation.

I call this the variability of opinions and judgment. It might seem like a deviation from the subject of the *balanced budget*, but I dare to consider it a step toward the core of the problem: first, I remember the stories I heard as a child about alchemists, the people who tried to make gold for themselves and for the kings. They tried it until young science at the beginning of the age of the enlightenment proved it to be impossible. Later, when the machine became a symbol of progress capturing human imagination, eager inventors searched for the perpetu-mobile, the perpetual motion machine, until again progressive scientists proved that this would be a physical absurdity.

I find interesting the story of the alchemists and the inventors of the perpetual motion machine because of a rather astounding fact. Constant failures to achieve those imagined goals have never been accepted as sufficient proof **that it cannot be done**. Furthermore, scientific proof has been reluctantly accepted; and without this proof, I am convinced that people would still try to make gold and to invent the perpetu-mobile.

And this brings me back to the *balanced budget*, and as a side issue, to inflation. I remember, as a little boy at home, listening in awe to my father and his colleagues discussing the budget and inflation at parties. There was an old professor of economic anthropology and economic history who used to say "Gentlemen, you are barking up the wrong tree. Since money exists, we have unbalanced budgets and inflation. So why not accept the facts? You know, all secretaries of finance, since ancient times, tried both: they tried to avoid inflation and have a balanced bud-

get and almost never were they able to do it. Does it mean they were all incompetent and stupid? Or does it mean both phenomena are embedded in (a) the nature of money and (b) in the human psychology? If you accept (a) and (b), then the problem is not how to solve the unsolvable, but to learn how to live with it."

I remember well the long silence which followed the old man's remark until a young rabbinical student started to laugh. "Gentlemen," he said, "I admire your questions. But, no offense intended, we Jews have known this for over 2000 years, when we suggested the jubilee of the old testament to cancel all debts every 50 years and start with a new accounting system."

I cannot claim that I, as a child, understood too much of the conversations between my father and his friends, but I got a feeling of uneasiness. Here were a group of highly educated men and it seemed to me that everyone had his own opinion, his own point of view, and defended contradicting positions. I must say, I was sorely confused. And in school sometime later, during the depression in Europe, I overheard the conversation of some teachers that made a lot of sense to me. They talked about the budget and one asked why the government can have a deficit when everybody else—a private person or a company—cannot spend more than he earns. I brought this wisdom to the attention of my father and had to listen to his explanations. He started by defining sovereignty, an attribute to the state in its totality, but not to a person or company, living and operating within the state. The state (or the nation) can make laws, have an army, and foremost make money, but not the entities within the state.

Those memories from my youth formed my thinking and mental preconditioning toward all economic theories.

The first book I selected for this theme review was Malabre's *Lost Prophets- An Insider's History of the Modern Economists.* The reason I started with Malabre is relatively simple. He is a learned economist and an economic reporter for the Wall Street Journal. His book is immensely readable, free of professional jargon, full of humor, without preaching any particular economic dogma. He simply reports with complete lack of respect, the failures of the great economists to predict the future. In his section "Budgetary Bafflement" (page 83) he pits (most politely) experts against experts. He starts out with the Eisenhower administration esteem for balanced budgets and discusses the relationship between the behavior of the economy and the state of the federal budget. He says that during the Kennedy administration, this was much more difficult to evaluate than at the end of the war when the pent-up demand of consumers, flush with savings that had accumulated during the war years, was released.

Then, he skips ahead two decades and refers to a 1983 conference, sponsored by the Federal Reserve Bank of Boston and organized to address the question: *Just how much should Americans worry about the rising sea of red ink engulfing the federal budget?* Malabre calls this conference "unintentionally hilarious."

Reagan Administration Treasury Secretary Donald T. Regan played down the importance of the budget deficit, but Martin Feldstein, President Reagan's chief economic advisor, warned that the outlook would be dark indeed if the red ink kept rising. Other speakers included Benjamin M. Friedman, a Harvard economics professor and a director of the National Bureau of Economic Research, followed by Albert M. Wojnilower, the chief economist of First Boston.

Friend Benjamin (excuse my use of first names) stressed cause for concern about the unbalanced budget and how it would impede capital formation. But Albert, known as a relative pessimist on economic prospects surprised the audience by stating that under certain circumstances, a larger deficit might well be associated with larger profits and investment. Albert concluded by saying, "The budget is like the weather: Everybody complains about it but nobody does anything about it, and no one is expected to." This last remark supposedly created some friction between Benjamin and Albert.

Malabre reports that another speaker, Professor Robert Eisner of Northwestern University, blamed the deficit essentially on inappropriate accounting methods at the federal level and argued that the budget deficit was in large measure an illusion. In particular, Eisner explained in his book, *How Real is the Federal Deficit?*, that a deficit that finances construction of our roads, bridges, harbors, and airports is an investment in the future. Expenditures to preserve natural resources or educate our people and keep them healthy are an investment in the future. But, under federal accounting procedures, such investment is regarded as additional red ink.

Malabre reports more about such differences of opinions. His section about "Budgetary Bafflement" is both amusing and deeply disturbing. It seems that the pro and con expert groups are talking about two entirely different subjects:

- Eisner, representing one group, talks about the physical economy, about bridges and airports, about construction and roads . . . about what can be and should be done.

- Feldstein, representing the other group, talks about the symbol economy, expressed in money.

Nothing demonstrates the differences of point of view more drastically than the Eisner-Feldstein disagreement, or ideological tunnel vision.

To me, the modern and not so modern economy always have two sides, like the two sides of a coin. The one side is the physical economy and the other side is the symbol economy. My colleague at DSMC, Professor James Abellera, calls the layer in between the ideological connection between the two. If you accept my analogy with the coin, you will also accept the trivial fact that both sides of the coin must be the same size. Think about this for a moment as a brain teaser and permit me to recall an event of the history of the Weimer Republic between 1930 and 1933. Germany had more than 6 million unemployed. The workers' unions requested an employment program to be financed by credits. The conservative government under Bruning refused in the interest of a balanced budget and in the election in July 1932, Hitler, the sole supporter of such a program, won.

This illustrates that the Eisner-Feldstein conflict is not necessarily new and also illustrates the possibility that the right decision of the moment can be catastrophic in the long run . . . think about it. Let me close my comments about Malabre's book with a question: Would it not be beautiful if we could combine and coordinate the Eisner-Feldstein approaches into a single system to everybody's benefit?

Next I turned to Eisner's *The Misunderstood Economy.* In particular, I selected Chapter 5, titled "Sense and Nonsense about Budget Deficits" (page 89).

The chapter starts with a quote from John Maynard Keynes book, *The General Theory of Employment, Interest and Money.* Then the author uses a 1953 quotation from President Eisenhower relating the budget to unemployment and the government's responsibility to fight it as much as possible. Next, he addresses balanced budget ideas of the Democrats, the Republicans and Ross Perot and asks a Gallup Poll question: "Which is more important, creating jobs or reducing the deficit?" Sixty-five percent responded with "creating jobs."

Eisner, at least implicitly, is talking at the same time about two related, but different subjects: first, he talks about purely economical problems, and second, about a political, moral subject. He is most careful with his statements and always searches for a balanced view. His discussion of measuring the deficit, referring to the difference between accounting principles in the private and public sector is most interesting. He is saying that by changing our accounting system, the deficit would be not much of a problem. If the government were a private company, all past investments in the infrastructure, such as roads, ports, dams,

power stations, and so forth, would be accounted as assets. Of course, this could be done in different ways: either as **past investment** or by its **market value** or **replacement cost**. Eisner does not discuss the different ways of accounting, which are subject to the law of the land. But regardless of the selected method, a private company would be immensely wealthy and to "be in the red" almost a joke, because with these enormous assets you could borrow almost any amount to correct or obliviate temporary cash-flow problems, which is implied in his table J, by listing the Debt/GDP ratio from 1939 to 1993 with a quantum jump for World War II (WWII). This, in turn, clearly implies that winning a war is more important than a balanced budget; again, we are back to a political-moral issue. Just remember President Roosevelt's words: "Do not worry about the deficit, we owe it to ourself." In a footnote he gives what he calls, an "explanation with elementary algebra."

Then Eisner asks two questions: "How do deficits hurt?—or do they?" He starts out with the statement: "What is written and said about the damage done by federal budget deficits is sheer nonsense, no matter how often repeated." He talks about the position of a sovereign government and about a repayment in cheaper dollars . . . after inflation. But again, he is extremely careful in choosing his words. He emphasizes that even a sovereign government cannot print money without control: this would lead to hyper-inflation as experienced after World War II in Germany, Austria, and Hungary. However, a little controlled inflation might be a blessing for the borrower, *albeit* a curse for the lender.

This interpretation is somewhat confirmed by Eisner's next subtexts: "Spending our Children's Money" and "And Inflation?"

He relates the spending of our children's money to taxes and interest rates and states, "We are told that large deficits will cause inflation. The first answer to this is that we have had some large deficits in the last decade and inflation has declined sharply." And when he turns to deficits, he states, "In general, deficits can be too small as well as too large." In short, Eisner implies that the truth is somewhere in the middle—like almost everything in life. He is essentially saying that while a little bit of a deficit is good, too much or none at all is harmful for the economy of a nation.

In the next two subsections, "Are deficits irrelevant?" and "How deficits do matter," Eisner disputes a school of thought led by Harvard's Robert Barro, which argues that deficits essentially do not matter. Then he lists David Ricardo's view that government borrowing instead of taxation may increase the people's after-tax income. Next he returns to the mainstream argument that deficits do matter and refers to the works of Gottfried Haberler of the conservative American Enterprise Institute

and to A.C. Pigan, a "classical" target of Keynes at Cambridge. Eisner continues to recall the expectations for a recession at the end of World War II based on the debt/GNP ratio of well over 100% in 1946 and calls the (thank God) erroneous prediction as part of the background and motivation of the work of Nobel-laureats Milton Friedman and Franco Modigliani developing our modern theory of the consumption function, which he tries to explain in plain English by giving a hypothetical example.

Eisner's arguments are often on both sides of the fence; but definitely, they should serve as an incentive for the student of the economy to dig into economic philosophy and history. In short, he fulfills his mission as a teacher. He implies that absolute numbers (in dollars) of property are rather meaningless and only indexed numbers (with constant purchasing power) count; because otherwise, inflation might distort the number game.

In the next subsection, "The Short Run: Impact on Consumption, Output and Employment," Eisner provides graphical statistics about changes in prices, employment, and real GDP. He brings in investment-aspects (beside others) and quotes Oscar Lange (1938) about an "optimal propensity to consume." He tries to explain the interaction between consumption and investment and the "crowding out" of investment because "there is no more capacity to increase both consumption and investment." He continues to talk about the balance of international payments related to export and imports.

His arguments get more and more involved and it seems to me, he wants most correctly to say that anything and everything in the economy hangs together. We can never consider one single aspect alone and ultimately, all is driven by the psychological reaction of all people to any new situation, resulting in decisions to save or to borrow based upon hope or fear about the future.

In the last subsection, "Deficits, Total National Saving, and our Future," Eisner represents himself more from a philosophical side. He stresses the significance of public investment in the infrastructure and the intangible investment in education, training, research, and the basic services of public security; and again, he tries to support his judgment with graphical statistics. Unfortunately, his arguments get more involved and sophisticated to the point where the uninitiated either can accept his argument in awe, or else be completely baffled, perplexed, or irritated.

Closing out Eisner, I must say he presents the subject in fascinating form, *albeit* not always easy to understand. He highlights economic history in its relationship to peace and war. So I ask these questions: Will the end of the Cold War and our success or failure to capitalize on the

"peace-dividend" change again our views about the deficit? And, what will happen if every developed nation has a deficit, like all the members of the European community according to the agreement of Maastrich, where the members of the *European Currency* established requirements no one is able to fulfill. I will return to this at the end of my review.

Eisner seems to be one of the few professional economists without tunnel vision. He is willing to consider throughout his book all possible points of view—at least where there is some logic involved.

Next I looked at Davis's *Making America Work Again.* I selected Davis's book in order to illustrate how opinions—and, of course, priorities—can change in response to political reality. *Making America Work Again* was published 12 years ago and it represents thinking at the peak of the cold war. The book is a call for victory, a call to subjugate all considerations for the fight and defeat of the Red Empire and the communist danger. There are no ifs and buts. All is clear and rudeness of expression has its purpose.

In the subchapter, "Capitalistic Socialism: Taxes, Budgets, and Deficits," Davis describes the superiority of the capitalistic system to control the economy with taxes, thereby eliminating the need for revolutionary upheaval and confiscatory actions. In the next subsection, "The Balancing Act: The Greatest Show in Town," he indirectly praises frugality, only to be suspended in times of war, but stresses that war-related deficits are seen as essential but temporary extraordinary expenses irrelevant to basic economic policy. He concedes that deficits gradually become immeasurably seductive, until the notion of a balanced budget begins to seem outdated, conservative, and unnecessarily regressive and the popularity of the budget deficit was properly misused to gain political advantage by all parties. He calls the Nixon Administration's first large deficit budget a fiction, because it was called a "balanced full-employment" budget; a fiction leading to the totally imbalanced behavior of the political leaders and making the projections of utopian statistics a matter of routine. After Nixon, he attacks Presidents Carter and Reagan for predicting a surplus and ending up with an increased deficit and blames both for the same utopian economic projections.

Thereafter, social transfer payments are attacked until he starts to talk in a subsection, "Vietnam: War is Peace," about military spending in the name of economic stability, describing it as only another case of the cross-eyed logic that transplants depression thinking into periods of relative prosperity. Then he refers to the critics of President Roosevelt's New Deal, claiming that it was the war, in fact, and not the recovery program, that brought us out of the depression. And he accuses the critics of ignoring the differences between financing wars and economic

recoveries. He ends with the traditional wisdom that it is not possible to have guns and butter at the same time.

In his subsection, "The Pentagon Years," Davis states that defense spending fires inflation by draining resources that might be put to better use and that "our economic theorists tell us, and with good reason, that capitalism does not need a war economy in order to survive. Depression can be averted through fiscal and monetary policy, that is, tax cuts and government (deficit) spending; like in building new factories, better roads and schools and similar valuable things."

Next he attacks the high overhead in the defense industry and brings up Grumman's apparent failure and inability to build efficiently or reliably the civilian *flexible* bus sold to cities.

In his last section, "Targets for Planning," Davis concentrates on upgrading military manpower, the mandatory draft, turning energy to peacetime production, the essentiality of profits for motivation—but not a single word about economic issues with regard to planning. Only at the end of his book does he return to economics, criticizing Reagan, Kennedy, Johnson, and Nixon for deficit spending.

He does not forget Milton Friedman for advocating indexation as merely disguising an unwillingness to accept discipline and closes with "The Lorelei of the Lafferites."

It is difficult to comment on Davis's book. He seems to try to please the ultra-conservatives and the ultra-liberals at the same time. Many readers will reach for an antacid, but conservatives at different times than liberals. Regardless of political leaning, only a fool would disagree that winning a war is more important than anything else. On the other hand, only a fool may agree with his extreme views on the economy; he reaches the extreme on both ends of the ideological scale. Or does he just try to win readers from all sides of the spectrum? I do not think so, because the text is of overwhelming arrogance.

For Davis, everybody seems to be a fool—only he is right. And what does he mean by being right? Does it mean a balanced budget under all conditions or to hell with the balanced budget when it serves political goals? For Davis, no middle ground exists.

Brewer's *The Sinews of Power* is book number four in our review. Brewer is a former professor of History and Literature at Harvard and now at UCLA. The book is a masterpiece, as may be expected of someone of his stature who has, at the same time, a deep understanding of the interactions between national military power and economic power. The book—more than 250 pages of text, supported by nearly 700 references—is free of any economic ideology, but amply supported by statistics, in the form of tables and graphs.

It is a fascinating book about the way Great Britain became the dominating world power at the time. It talks about the East India Company. It underlines the importance of economic and social resources—of capital and labor, wealth and manpower—to becoming a great power. Most fascinating is the description of "The radical increase in taxation and the development of public deficit finance (a national debt) on a unprecedented scale, and the growth of a sizable public administration, devoted to organizing the fiscal and military activities of the state."

In the introduction, the author says that by today's standards, measured on the requirements of the modern International Monetary Fund (IMF), Great Britain would have been unable to get a loan.

The relationship between military and political power to financial aspects is most interesting. It seems that history teaches us that the winner can be never wrong, the loser never right. If Rome had lost against Carthage, the entire world history would look different. But I am supposed to talk about economics, not history.

Krugman's *Peddling Prosperity* is the fifth and last book in this review. It is a pleasant book to read, written with a lot of humor and a minimum of arrogance. On the fly page, Krugman quotes from Keynes, amplifying the power of ideas of economists and philosophers both when they are right and when they are wrong to the practical men. In the preface, Krugman states that "the subject of economy is harder than physics; luckily it is not quite as hard as sociology."

Why does Krugman say this? Quite obviously, he refers to the unending choices possible for any economic action from the simplest to the most complex. Your preference for a particular soap or a specific car, your judgment of the problem of unemployment or the value of a *balanced budget*—provided there is a trade-off—will depend on your social position, religion, philosophy, or world view. And those options are unlimited and unpredictable. Now to Chapter 6 of his book, "The Budget Deficit."

Krugman is really not saying anything that has not already been included in the other references. But, I think he says it better and clearer. And foremost, he abstains from rude judgment about the actors in economy. In short, he tries to act like a gentleman. He says "The federal government has run a surplus in only one year out of the past thirty. Why blame Reagan for continuing the trend?" Thereafter, he concentrates on the deficit trend in terms of the size of its debt relative to the size of the tax base. Krugman is willing to accept a deficit, provided it is not too large. "No extremes please" seems to me a most reasonable position. He tries desperately, and mostly quite successfully, to avoid harsh critique on opposite points of view between the liberals and the

conservatives. He simply prefers to compare opinions and the shift or change of opinions. He states that "once upon a time, it was liberals who were soft on budget deficits . . . liberals always wanted to spend more on social programs, and had trouble finding ways to pay for them. On the other hand, conservatives were tight-fisted types who constantly warned about the menace of government borrowing."

Thereafter, he shifts to the supply-siders and "once come to power, there was an almost comic role reversal: liberals became the stern prophets of fiscal doom, while George Bush adopted McFerrin's 'Don't worry, be happy' as his unofficial theme song." Too bad I cannot quote the entire chapter in this review. But I strongly recommend it as appropriate reading material. It is unique in its clarity and tolerance.

In a subchapter, Krugman introduces the term "hidden deficit," as supposedly springing from three sources: (1) the misregulation of financial institutions like saving and loan associations; (2) too little investment in infrastructure; and (3) too little provisions (or thinking ahead) about the increase of retired people to active workers.

I like to abstain from any comment on the misregulation of the financial institutions. But I think you cannot have a *laissez faire* philosophy and government control at the same time. Such requirement would be a logical contradiction.

I fully accept the second claim, the hidden deficit resulting from too little investment in infrastructure. I have noticed that whatever smart engineers build needs maintenance. And just as with my car, proper maintenance might be cheaper than to run the car without maintenance until it collapses and then buy a new one. To be more specific, the maintenance of the infrastructure *and* the existing dedicated investments are the alpha and omega of a healthy economy. Without this maintenance, any modern economy will collapse. And we have an example for this: The former USSR. The often plentiful food production was useless and food rotted in warehouses because there was no working distribution system (roads, railroads, etc.), and some of the most modern factories dilapidated rapidly to scrap as the maintenance problem was utterly ignored. You may call this "ideological stupidity."

As reviewer, I have some problems with (3), the relation of workers to retirees. First, from a purely economic point of view, we need the retired people as customers for the products of the workers (with increasing productivity), and second, from a moral point of view, we cannot exterminate the retirees . . . we still love our parents. Beside, this is not a prototypically American problem. The worker/retiree ratio is much worse in Sweden, Germany, Switzerland, Austria and almost all West-European countries, first, because of the demographic age trend, and

second, because of the rigorous retirement age limits (mostly 60 for women and 65 for men).

Now a few overall comments: But first, an apology may be in order. It might be that I misused this review to sneak in some of my personal views on the subject. But, on the other hand, this should be the privilege of an old teacher, who has never taught the cookbook of the day, but was foremost interested in bringing his students to the point of "thinking for themselves," convinced that they can do it, but seldom learned it and rarely dared to practice it.

Now my final comments:

- First, I am utterly surprised that none of the five authors addresses the question of where to get the money from for an unbalanced budget. A sovereign government can print the money (with all dangers involved) or it can borrow the money from its own population or from foreigners (with all inconveniences of later repayments). It would be interesting to hear the comments to this point from experts of different orientations.

- Second, from my lecture notes on "The Europeans," I like to bring the requirement as established in Maastrich to entitle a nation to enter the Common-Money-Union of Europe. Just recently, three other nations have been accepted in the European Community (EC), but not listed in the table. They are Sweden, Austria, and Finland, former members of the European free trade associates (EFTA). None of the 12 listed nations of the EC was able to satisfy the four requirements for long term interests (A), the rate of inflation (B), the national debt (C), or the deficit (D).

The table shows that not one of the 12 members was able to satisfy all four requirements and only one member, Luxembourg, was able to satisfy the debt and deficit requirements. And this brings me back to my introductory remarks to this review, talking about the alchemists and the inventor of the perpetu-mobile.

Applicable to the *balanced budget*, we may ask the impertinent question; if all secretaries of finance are the epitome of incompetence; or the most reasonable question; if the requirement for a balanced budget might not be a most unrealistic pipe dream. But, the same question about the reasonableness to expect a balanced budget could be applied to the reasonableness to expect an inflation free economy. If you are interested in this question, I recommend Don Paarlberg's book, *An Analysis and History of Inflation* (Praeger 1993). Paarlberg is Professor Emeri-

Table 1.
**REQUIREMENTS TO ENTER THE COMMON-MONEY-UNION

A — LONG TERM INTERESTS (OVER ONE YEAR)	9.2%
B — RATE OF INFLATION	2.8%
C — NATIONAL DEBT IN % OF GNP	60.0%
D — YEARLY DEFICIT IN % OF GNP	3.0%

**DE-FACTO SITUATION (1993)*

SHOULD	A 9.2%	B 2.8%	C 60.0%	D 3.0%
COUNTRY:	IS:			
BELGIUM	7.0	2.7	X 140	X 6.5
DENMARK	6.0	1.4	X 65	X 3.8
FRANCE	6.0	2.0	58	X 5.2
GERMANY	6.0	X 4.0	50	X 4.0
GREAT BRITAIN	7.0	1,8	45	X 8.5
GREECE	X 22.0	X 13.0	X 90	X 10.5
IRELAND	8.0	0.9	X 95	X 3.5
ITALY	8.0	X 4.3	X 115	X 9.5
LUXEMBOURG	7.0	X 3.2	10	1.0
NETHERLANDS	7.0	2.0	X 80	X 3.5
PORTUGAL	X 13.0	X 5.8	X 65	X 4.5
SPAIN	9.0	X 5.0	55	X 5.5

* IN ROUND FIGURES
X NOT QUALIFIED

tus of Agricultural Economics at Purdue University. He served in the administrations of Eisenhower, Nixon, and Ford. Thereafter, you may draw your own conclusion, but I expect you will ask the same question as I did.

Maybe the problem is not how to avoid the unbalanced budget and inflation, but rather to learn how to live with it . . . or do we prefer the mental state of the Alchemists?

If you are interested in how experts can disagree, I recommend reading the essay, "Competitiveness: A Dangerous Obsession" (Krugman, March/April 1994) and comments, "The Fight over Competitiveness" (Prestowitz, et al., July/August 1994), both in *Foreign Affairs*. They are followed with a reply from Kurgmann.

The essay and the comments illustrates the diversity of points of view or what I called at the beginning of the review the "variability of opinions and judgment." You also will understand my quotation at the beginning: " Every economic theory is correct . . . sometimes. Every economic theory is wrong . . . mostly."

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Material proposed for the *Acquisition Review Quarterly* should reflect scholarly examination, disciplined research, and empirically supported experience in the fields of defense systems management and acquisition management. While defense acquisition is our primary focus, material addressing other fields of management will be considered. Manuscripts supporting the Defense Acquisition University commitment to improving the acquisition process and the professionalism of the acquisition workforce are especially welcome. Full-length articles should not exceed 4,000 words with supporting text and graphics. Articles of 600-1,500 words describing new practices, programs, or techniques may also be considered.

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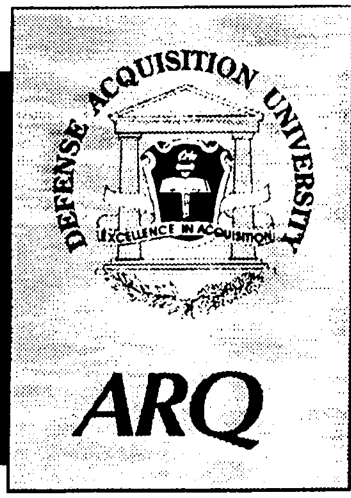

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